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A SYMPOSIUM ON THE CLASSIFICATION AND NOMENCLATURE OF GEOLOGIC TIME-DIVISIONS.

THE infelicities which arise from the uncertain use of terms in the discussion of geologic time-divisions are more or less fully appreciated by every working geologist. The peculiar difficulties which the varying and often inconsistent use of terms imposes upon the student of geology when he leaves the narrow confines of his text-book and tries to use the current literature of the science, can only be realized by those teachers who have encouraged this broader method of study and conscientiously feel responsible for the results. Not every text-book, even, is consistent with itself. It is too much to insist that it should be consistent with general usage until a consistent general usage is established. The importance of a more systematic classification of time-divisions and rock-series has been recognized by the international congresses of the last two decades. The limited results that have been reached by the efforts of these congresses seem to indicate that the problem must be worked out by gradual approaches through tentative efforts. It perhaps also indicates that the problem must be in large part worked out in the great provinces or in the individual continents separately as a preliminary to intercontinental coördination. Not a few geologists who heartily sympathize with the effort to secure more uniform and better practice are yet quite unwilling to have a rigid system imposed by the vote of a body of so uncertain composition as

an international congress. Quite aside from doubts connected with such an enacting body, there are those who question whether we have reached that stage in the development of interpretations and correlations which warrants the formal adoption of a universal system of classification and nomenclature. Fully sympathizing with both these classes, we none the less feel that these considerations only emphasize the importance of those preliminary and tentative efforts through whose agency a satisfactory system is to be worked out in time by the method of concerted trial and continued rectification. Especially does it seem important to proceed as fast as may be with the evolution of a system appropriate to our own continent as a preliminary to the establishment of an intercontinental system.

Certain phases of a system of nomenclature involve little more than a choice of terms. To this extent only a consensus of preference is needed to inaugurate a common practice which shall become conventional. In most cases, however, the choice of terms is connected with a choice of ideas, and a consensus is less readily reached. Whether a community of preference can now be reached or not, it can scarcely be questioned that we should work toward such a community, if possible, rather than away from it. We appear to have been receding from uniformity, rather than approaching it, for the past two decades. The result is a disturbed practice and a confusion of terms infelicitous alike to geologist, to teacher, and to student.

The more important phase of the question lies back of the selection of terms and relates to the questions: What divisions, or what order of divisions, shall be chosen for formal nomenclature, and upon what criteria shall the divisions be determined? Granting that these questions cannot be answered finally at present, or in the near future, it is still urgent to inquire: By the use of what system, provisionally adopted for current use, can we best work on toward better systems in the future?

To draw out opinion on the subject, a series of questions was prepared by one of the editors of this JOURNAL (Professor Salisbury) and submitted to several American geologists with a

view to inaugurating discussion. The questions were made specific to invite definiteness in the replies. They were made to overlap somewhat to facilitate specific answers to different aspects of the subject. It was not intended to specifically advocate the scheme presented, but merely to submit a tangible sketch for discussion. A portion of the replies are printed in this number. The discussion of the subject by others who may be interested is invited. The questions submitted are as follows:

1. What classification of time (and terranes), say to the third or fourth division, seems to you best adapted to North America? If you are ready to express your opinion concerning such a classification to the second division, but not farther, please do so.

2. To what extent is it desirable to adhere to European standards, if some other classification is better adapted to North America?

3. What noun should be used in connection with the adjectives *Palæozoic*, *Mesozoic*, etc., 1° when time is meant, and 2° when formations are concerned? For example, Palæozoic *era?* Palæozoic *group?*

4. What noun should be used in connection with the primary subdivisions of the Palæozoic such as Cambrian, 1° when time is meant, and 2° when formations are concerned? For example, Cambrian *period?* Cambrian *system?*

5. What is the best noun to be used in connection with divisions of the third order, such as Lower Cambrian, Middle Cambrian, etc.? For example, Lower Cambrian *epoch?* Lower Cambrian *formation?*

6. Ditto for divisions of the fourth order.

7. Would you approve of the separation of the sub-Carboniferous and the Permian as divisions coördinate with the Carboniferous proper, the Devonian, etc.

8. If you approve of the separation of the sub-Carboniferous from the Carboniferous, as a division of the second order, would you approve of retaining the name sub-Carboniferous or Lower Carboniferous, or would a new name be better, say Mississip-

pian? The repetition of terms involved, if the term sub-Carboniferous or Lower Carboniferous and Carboniferous continue to be used as now, is so great as to be very confusing to students. Those who have not dealt with students beginning the study of historical geology may not be aware of the difficulty involved in such a system as the following:

Carboniferous,
Permian,
Carboniferous,
Sub-Carboniferous.

9. Would you approve of the separation of the Cretaceous into two divisions coördinate with each other, and each coördinate with such divisions as the Devonian?

10. If so, would you approve of the retention of the names Lower Cretaceous and Upper Cretaceous, or should one of these divisions, presumably the Lower, receive a new name, say Comanche?

11. How should the Cenozoic be subdivided?

12. What is the advantage of the term *Canadian*, and the corresponding *Trenton*, in the following classification?

Ordovician - -	Trenton	Hudson River	
		Utica	
	Canadian	Trenton	
		Chazy	
		Calciferous	

Why not instead?

Ordovician - - -	Hudson River
	Utica
	Trenton
	Chazy
	Calciferous

13. Will you express your opinion concerning the following outline where the divisions are carried to the second order?

Era (for time) Group (for rocks)	Period (for time) System (for rocks)
Cenozoic - -	Pleistocene
	Pliocene
	Miocene
	Eocene

Mesozoic	Cretaceous (Upper) Comanche (Lower Cretaceous) Jurassic Triassic
Palæozoic	Permian Carboniferous Mississippian (sub-Carboniferous) Devonian Silurian Ordovician Cambrian
Proterozoic	Keweenawan Upper Huronian Lower Huronian
Azoic	Archæan

14. What would you say to this plan of classification:

Era	Group
Period	System
Epoch	Series
Stage	Formation

CONTRIBUTION BY JOSEPH LE CONTE.

I hereby give answers to your questions as briefly as possible:

1. I am not prepared to go further than divisions of the second order.

2. European standards, as first in the field, must be followed as far as possible, but should be modified, if necessary. But eventually we must have a world standard, at least for divisions of first and second orders.

3. I think — Era and Group are best.

4. " " Period and System are best.

5. " " Epoch and Series are best.

6. " " Stage and Formation are best.

7. (*a*) *Sub-Carboniferous* is certainly coördinate with Carboniferous proper, but I do not think that *Permian* is. Witness the tendency to unite Carboniferous and Permian under Permo-Carboniferous.

(*b*) But I much doubt that these are coördinate with *Devonian*.

8. "Mississippian" serves our American purposes well, but, if used, ought to be coupled with Lower Carboniferous as synonym, as you have done.

9. Cretaceous ought to be divided into two coördinate divisions, but I do not think these are at all coördinate with Triassic, Jurassic, or Devonian. They must be regarded as sub-periods.

10. I think it best, therefore, to retain the names Lower and Upper Cretaceous; but, if a new name is used for the lower division, why not call it "*Shasta*." It was certainly first recognized there.

11. I am in favor of the fourfold division of Cenozoic you propose, although I fully appreciate the reasons for uniting Miocene and Pliocene into Neocene. Tertiary and Quaternary might well be abolished, as Primary and Secondary have already been.

12. I see no sufficient reason for the names Canadian and Trenton as sub-periods. Better divide Ordovician at once into epochs, as you suggest.

13. I like your schedule of divisions of first and second orders except as regards the Cretaceous and Carboniferous, as already explained. Also, I do not like the term "Azoic," although not prepared to suggest anything better.

14. I fully endorse your general plan of classification for time and strata. JOSEPH LE CONTE.

CONTRIBUTION BY G. K. GILBERT.

So long as historical geology continues to be a living science no definite system of nomenclature can hope to be permanent, nor even, perhaps, to give temporary satisfaction to a majority of geologists. Nevertheless, as intimated by the JOURNAL'S circular letter, teachers and geological surveys must have definite systems, and so the task of making and remaking them is a sort of necessary evil.

(Questions 1 and 2.) Though time is universal, faunas and histories are more or less local. A refined time scale cannot be used to advantage in the correlation of formations widely separated. Therefore, only the major orders of a time classification should be treated as universal, and the minor should be recognized as local. I suggest that the line of discrimination be arbitrarily drawn between divisions of the second and third ranks, periods and epochs.

Pursuant to this suggestion, I propose the following auxiliary criterion for periods (not replacing but supplementing other criteria): Periods should have such magnitude that their application to the correlation of formations anywhere in the northern hemisphere will yield areas of certainty which are large as compared to the unavoidable zones of doubt.

This criterion is used in the selection of the subjoined scheme of periods, but is subordinated to other considerations in the admission of Pleistocene and Algonkian. Jurassic and Triassic are given separate place despite their broad zones of doubt when applied to American terranes, because the breadth of those zones is due to dearth of the most important data for correlation, marine fossils.

Periods.

12. Pleistocene (or Quaternary).
11. Tertiary.
10. Cretaceous.
9. Jurassic (or Jura).
8. Triassic (or Trias).
7. Carboniferous.
6. Devonian.
5. Silurian.
4. Ordovician.
3. Cambrian.
2. Algonkian.
1. Archæan.

(3.) Four time-nouns have been used in this rank by various authors: *Era*, *age*, *eon*, and *time*. *Time* cannot be spared from its general sense. Of the others *eon* alone has a good connotation for this place; its untechnical meaning always includes long duration.

Group is not well placed in this rank. Prevalent American usage, which puts it next above the unit *formation*, is in harmony

with the ordinary meaning of the word,—an aggregate of individuals (not an aggregate of aggregates).

(7.) No.

(7, 8.) I like Mississippian as the title of an American subdivision of the Carboniferous period. There is need of a complementary, coördinate, American, geographic name (or names).

(9.) No.

(14.) I prefer:

Eon - - -	System (or Series).
Period - - -	Series (or System).
Epoch - - -	Group.
Stage (or Age) -	Formation.

(Comment on 5, 8, 10, 13.) The adjectives of space relation, *Lower* and *Upper*, should not appear in a time scheme. The prefixes *Eo-*, *Meso-* and *Neo-* (proposed for a somewhat different use by Williams) seem appropriate for the indication of indefinite portions of any time unit. For definite parts separate geographic names are preferable. G. K. GILBERT.

CONTRIBUTION BY WM. BULLOCK CLARK.

I think that the questions, which you have raised regarding the use of terms in geological classification, are most timely. If a discussion of the subject can aid in bringing about some unanimity in the employment of these terms on the part of geologists, you will have performed a great service.

I am inclined to take the position that, from the very nature of the case, a universal system of stratigraphic equivalents cannot be employed for the chronologic terms. The chronologic divisions, as we all recognize, are at best highly artificial, while the stratigraphic divisions are natural and definitely determinable units. The term "formation," for example, has come to be rather widely used to embrace deposits formed under approximately similar conditions whatever the time element involved, and may or may not be separated from overlying or underlying formations by an unconformity.

Accepting the chronologic terms which you have adopted,

and which, I think, cannot be improved upon, certainly to the third division—viz., era, period, epoch—it may be possible to find the formation as the equivalent of a portion or the whole of any one of these time divisions, excepting, perhaps, the era. To attempt to restrict it, therefore, in all instances to any chronologic division, large or small, would seem to me unwise.

Furthermore, I think that a different series of names should be applied to the formations and their subdivisions than to the time units. I should speak of the Palæozoic era or time, the Cambrian period, and the Upper Cambrian, or better, the Neo-Cambrian epoch, but of the Potsdam formation or the Shenandoah formation, the latter representing portions of the Lower Silurian as well as Upper Cambrian, and affording a good example of the formational unit. I prefer the prefixes Eo-, Meso- and Neo- to designate the epochs, as proposed by Williams. I think the term Stage more applicable to a division of a formation, whether characterized by a distinct fauna or not, than to a time unit.

In reply to your questions seven and eight regarding the later divisions of the Palæozoic, I should employ the chronologic terms Carboniferous and Permian, the former divided into Upper and Lower, or Upper, Middle and Lower Carboniferous, as the case might be. To be consistent the terms Eo-, Meso- and Neo-Carboniferous should be used. The Upper Carboniferous may be represented by Coal Measures made up of one or more formations; the Lower Carboniferous may be represented as in the central United States, by the Mississippian, or, as I should prefer, the Mississippi Group, made up of various formations. I should personally object to the use of the term Mississippian in a chronologic sense, unless the period term Carboniferous was to be permanently divided and the resultant divisions raised to the period rank. The reasons for such change, however, do not seem to me to be sufficiently strong. I think the widely extended difference in facies represented in the Upper and Lower Carboniferous tends greatly to accentuate the two divisions of this period.

These same reasons seem to me to apply equally well to the Cretaceous. Although there is a very considerable difference between the upper and lower divisions, it does not seem to me sufficiently great to warrant their elevation to equal rank with Devonian, Carboniferous, etc. I should, therefore, employ Comanche in its original sense as a stratigraphic term, and, as several formations are clearly recognized within the limits assigned to it, I should be inclined to speak of the Comanche Group.

I should prefer to divide the Cenozoic into Eocene, Neocene, and Pleistocene as the most widely recognizable time units, placing under the earlier term Eocene the subsequently named division Oligocene of von Beyrich and uniting Miocene and Pliocene into Neocene.

I can see little advantage in the use of the terms Canadian and Trenton, except as group names, to include the Calciferous and other formational divisions.

I prefer the use of Lower Silurian to Ordovician, as I do not think the term Silurian of Murchison can with propriety be restricted to the Upper Silurian. If the Upper and Lower Silurian are to be raised to period position, and Ordovician used, I think some other name should be substituted for Silurian.

WM. BULLOCK CLARK.

CONTRIBUTION BY S. W. WILLISTON.

I am greatly pleased with your attempt to reduce some kind of order out of the chaos that has been made in geological nomenclature. I think no one but the actual teacher of historical geology can appreciate the amount of confusion that now exists and the vexation that it causes both teacher and pupil.

To the first five questions I am not prepared to offer suggestions except this, that it will make very little difference what terms are used for the time and formation, provided there is uniformity. I am ready to accept and teach any system that receives the approval of writers on these subjects, and is used with tolerable fixity and uniformity.

7. To this proposition I would desire to enter a vigorous protest. Having worked in Kansas, where the Permian is best represented in this country, I can see no good grounds whatever for distinguishing between two groups in respect to which neither the palæontologist nor the stratigraphist can determine where the one begins and the other ends. Palæontologically there is nothing of sufficient importance to warrant the division into primary periods. It is true that, so far as we now know, the reptiles began in this time, but every palæontologist confidently expects that they will be found in the true Carboniferous, and in fact they have been found in Kansas in strata that are yet in dispute. Knowing less of the sub-Carboniferous, I cannot give an opinion here, but I do not believe there are any better grounds for division than between the Carboniferous and the Permian.

Classification of the time periods of the earth must inevitably follow the same rules as those applied in the classification of animals and plants, which in the end becomes one of convenience, chiefly. If we increase the number of primary divisions, as the tendency seems to be, the number will at last become so large that some future classifier will insist upon reuniting many of them under new and undesirable names. The chief divisions should represent, so far as possible, time periods of equivalent importance, and to say that the Permian period is an equivalent of the Carboniferous, or the Silurian, is certainly incorrect. Personally, I would rather see the Trias annexed to the contiguous divisions!

8. I should much prefer to see the name Carboniferous applied to the primary division and distinctive names given to the three subdivisions. There is a *very* great, almost intolerable, objection to using the name Carboniferous in two senses, or even the Carbonic and Carboniferous. I very much hope that the name Mississippian may be given to the lowest group, some good distinctive term to the intermediate, as Coal Measures, and Permian applied to the uppermost.

9. For many of the same reasons already given for the

Permian, I strenuously object to the subdivision of the Cretaceous into two primary divisions. Certainly, so far as vertebrate palæontology is concerned, there is no good reason for the division, and there are many opposed to it. I would rather prefer Upper and Lower, for the divisions of the Cretaceous, but would willingly see such terms as Platte and Comanche used.

11. I would prefer to have the Cenozoic divided into the Eocene, Miocene, Pliocene and Pleistocene. I believe this is the only logical system, unless, perhaps, the Oligocene is added. Nevertheless, I see great difficulty in superseding the much used Tertiary. Most assuredly there should be no distinction into "Tertiary" and "Quaternary," and, if Tertiary is used, its limitations must be widened to include the Pleistocene. This will be equally hard to do, and for that reason I believe, upon the whole, the best way is to drop the term Tertiary entirely.

14. I am quite ready to use the plan of classification given in my teaching and writings, if its use can become at all general. Fixity and uniformity are all that I ask for here.

13. The terms and divisions that I think ought to be adopted, so far as I have grounds to base my opinions upon, are as follows:

Cenozoic, - - -	Pleistocene,	
	Pliocene,	
	Miocene,	
	Eocene,	
Mesozoic, - -	Cretaceous,	Upper. Lower.
	Jurassic.	
	Triassic.	
Palæozic, - - -	Carboniferous,	Permian. Coal Measures. Mississippian.
	Devonian,	
	Silurian,	
	Ordovician,	
	Cambrian.	
Eozoic or Proterozoic,		
Azoic.		

I have done very little field or laboratory work upon the divi-

sions prior to the Carboniferous and refrain from expressing an opinion about them.

I very much prefer the use of European terms for divisions that can be correlated with tolerable exactness; otherwise distinctive American terms should be used.

I sincerely hope that you will bring some order out of what has been so confusing to both teacher and student.

S. W. WILLISTON.

CONTRIBUTION BY BAILEY WILLIS.

Your inquiries of May 5, concerning the use of certain common terms in geology and questions of classification, were duly received and have been carefully considered. In answering I beg to state that I express my personal opinion as determined by experience in practical field work and in editorial work on geologic maps.

The following answers are arranged categorically, according to the numbers of the questions to which they refer.

1. *Eras, Systems.* — Terms to be applied respectively to the grand divisions of time and the rocks representing them, as determined by the most important events of biologic development.

Periods, Groups.— Arbitrary divisions respectively of time and rocks within the eras and systems, designed to afford means of approximate designation of the position of any geologic record in the time scale. These should be applied consistently the world over according to the volume of stratigraphic evidence as checked by palæontology, but it does not necessarily follow that in North America they designate time divisions precisely contemporaneous with those distinguished in other continents.

Ages, Series. — Terms to be applied respectively to subdivisions of time and rocks less than period and group, but including a consistent sequence of biologic or lithologic changes without break. An age or series may include parts of two periods or groups.

Epochs, Formations. — Terms applied to designate the time

represented by the lithologic unit which may be mapped on a given scale and the lithologic unit itself.

Episodes for time, Lenses and Lentils or Stages for rocks.— Terms applied to local lithologic variations or limited rock masses which for purposes of discussion need to be defined, but are not of sufficient consequence to justify the distinction of a separate name.

I may briefly state my reasons for the above suggestions as follows: (1) I associate era and system because the classification is based on the broadest natural facts and is therefore systematic. (2) I associate group with period because both terms appear to me less precise and adapted to the arbitrary character of the unit thus classified. The division of time according to a scale of periods appears to me equivalent to the division of a column of mercury according to a scale of degrees to indicate temperature; whether the result be expressed in the arbitrary terms of Fahrenheit or Centigrade the fact remains unmodified. The simplest scale which will satisfy the needs of world-wide geology is to be preferred. (3) I associate age and series as both of them indicate a consistent logical sequence of events having their beginning and rounding out to an end, as in history we have the Elizabethan age and the series of events which characterize it. Age and series are natural divisions as distinguished from period and group, which are terms of the arbitrary scale. (4) I associate epoch and formation probably rather through custom than for any special reason, but I prefer epoch as a time designation to stage because the latter has a more concrete significance and might with equal aptness be applied to a subdivision of rocks. Indeed, if a geologist named to me the Medina stage, I should understand that the sandstone was referred to rather than the time for which the sandstone stands. Furthermore a stage appears to me to represent a temporary or very brief condition and to correspond in time with the term episode. The necessity for the fifth subdivision, corresponding to episode, frequently arises in detailed discussion, and is a means of avoiding complexity of nomenclature. Thus if a con-

'glomerate lens appears in the Medina formation it can be referred to as the Medina conglomerate lens or episode, without burdening the discussion with a new name, which the conglomerate should receive if it be considered a formation.

2. To that extent which promotes unity of classification without contradiction of fact and no further. In case of doubt whether European standards apply to North American facts, it is better to adopt a North American standard in accordance with the facts.

3. Palæozoic era, Palæozoic system.

4. Cambrian period, Cambrian group.

5. Lower Cambrian age, Lower Cambrian series.

6. Medina epoch, Medina formation.

7. No. The multiplication of period divisions does not in my judgment tend to the advantage of geologic students.

8. The absurdity of a double meaning for any term is apparent. The usage arises from the effort at excessive subdivision in terms of periods.

9. and 10. No. This question has been several times considered, and the requirements of the case are adequately met by the use of the terms Comanche age and Comanche series.

11. Pleistocene, Neocene, Eocene.

12. I should omit Trenton and Canadian as superfluous.

13. The proposed scheme contains an undesirable number of period divisions. The sets of facts and corresponding times represented in the scheme by Pliocene, Miocene Comanche, Jurassic, Triassic, Permian, Mississippian, and Ordovician I should transfer from the list of periods to that of ages, where I think they would be adequately represented.

14. Answered under 1. BAILEY WILLIS.

CONTRIBUTION BY C. R. KEYES.

If I understand the questions rightly it would seem more logical to attempt to answer the last one first.

Uniformity of terminology is the great desideratum of working geologists. The main drawback to the adoption of any

proposed scheme appears to lie in the disinclination of most writers to make any distinction between a technical and common usage of words. Terms that already have assumed special meanings should be used only in a technical sense. For expressing ideas in which a restricted meaning is not implied there are many common terms.

In geological classification a dual scheme has come to be so universally recognized that it is difficult to imagine that any other is possible. Yet, for local successions of strata a single set of adjectives suffices to designate both the subdivisions of time and those of substance. Hence, with five orders of terms to denote the taxonomic rank of the name used—and these appear to be all that will ever be useful in practical work—we have:

Order.	For Time.	For Rocks.	Example.
1.	Era	Assemblage.	Palæozoic
2.	Period.	System.	Carboniferous.
3.	Epoch.	Series.	Mississippian.
4.	Episode.	Stage.	Kaskaskia.
5.	Hemera.	Zone.	Pentremites Godonii.

The word group, sometimes used for the largest rock division, is so thoroughly incorporated in our literature in a different sense, and is generally so loosely applied, that it seems hopeless, and in fact very undesirable, to attempt to give it, at this late day, a technical meaning. Moreover, it is far more useful now, with its present indefinite application to any selected number of beds or subdivisions, than it could possibly be in a more restricted sense. Some other title should take its place for technical purposes. It makes little difference what it is. Its general adoption is the most important feature. Assemblage, the name here given, is merely suggestive. It is somewhat ponderous, but is expressive of the grand subdivisions.

Stage is a word associated not with the idea of time, but of place. It is, therefore, more properly applicable to the fourth structural order, interchangeable, perhaps, with formation. But the latter term may be extended without confusion to crystalline

masses also. As the stages are based largely upon lithological characters and receive local geographic names, the latter are followed by such words as limestone, shale, granite, etc., thus doing away with the technical title altogether. In general the word formation seems to be best retained for use in somewhat doubtful cases, where the exact taxonomic rank is questionable, but believed to be about of the fourth order; while group refers to any of the greater orders.

The time equivalent of the stage seems best expressed by the word episode. The word Time is also appropriate, and it more exactly corresponds with the historical usage to represent a generation.

The zone is a useful subdivision of the smallest unit usually recognized in this country, The name of its time equivalent is Hemera, proposed by Buckland. The zonal classification of the Ammonite-bearing beds of the Jurassic is an example.

Assuming the ultimate aim of every scheme of geological chronology to be to provide a means of paralleling stratigraphic successions more or less widely separated geographically, a practical question arises as to how far a general classification is applicable to a given region, and how far the local plan is capable of being expanded.

While the double geological scale is theoretically everywhere balanced, in practice the time element is given precedence at the more general end of the scheme, and the rock element at the more specific or local extremity. In the present state of our knowledge general correlation farther than series is beset by many and grave difficulties, and it is doubtful whether it is feasible to extend it beyond.

So far as concerns the first two orders enumerated in the plan already given, it seems desirable, for the present, to retain the names generally applied to the different "groups," even though they are largely European in origin and are not exactly expressive of the real conditions in North America. They are so thoroughly part and parcel of our literature that it would be revolutionary to supplant them. It is better to modify their

meanings somewhat, rather than discard them altogether. Besides they have entirely lost their local original significance. They are now abstract terms. In this country the data will soon be at hand for the construction of an entirely new chronological plan, having a purely physical basis, the biological criteria being ignored altogether.

In the third order there is an overlapping of general and local criteria. To express the time factor the words Early, Mid- or Middle, and Late appear appropriate; as Early Cretaceous. The simple Anglo-Saxon names are much more preferable than the long barbarisms, produced by the Greek prefixes Eo, Meso and Neo. Simplicity of terminology should be a cardinal principle if geological science is ever to receive the popular attention it deserves. For the rock scale, Lower, Median or Middle, and Upper are useful terms to indicate in a general way the corresponding subdivisions; as Lower Cambrian, Lower Carboniferous. Or, the latter titles may be used in a somewhat indefinite way, when the exact stratigraphic limits are yet unknown.

Here the local succession begins to assume importance and the general time factor to lose it. Each geological province has its own sequence of strata. A provincial geographic name is desirable, if possible with an adjective ending. Thus, we have for the Lower Carboniferous in the Mississippi province, the Mississippian series; in the Appalachian province the Poconon series, possibly; in the Great Basin province the Aubreyan series, perhaps. The number of series is thus not fixed for any system, as locally represented, nor for different localities. Yet the epoch of all is definite. The time may come when it is desirable to have some special name to cover all the provincial series of approximately the same age, but the condition of our knowledge does not yet warrant it. It is doubtful whether it would be any improvement on the simple Lower, Middle and Upper.

An ideal feature of geological nomenclature is uniformity of endings for all terms of equal taxonomic rank. With those of the first order this method already prevails. In the case of

those of the second order a variety of different terminations exist; but it is probably not advisable now to change them. However, these names are so few in number that they are not liable to cause confusion. The provincial titles of the third order are in large part yet to be proposed. For all these an appropriate original or provincial name is suggested, with the ending *an*, if possible. This leaves the countless horde of formations, or stages, the usual units of geological mapping, the distinguishing characters of which are based chiefly upon lithology, a clear field for unchanged, local, geographic honors. The zones are named from their leading fossils.

Our information regarding the geological subdivisions is so unequally distributed that at best a very unsymmetrical classification must be endured for the present. The following seems to be the most acceptable scheme for North America:

Era.	Period.	Epoch.	
Cenozoic.	Pleistocene.	Late or Recent.	
	Neocene.	Early.	
	Eocene		
Mesozoic.	Cretaceous.		
	——— ?		
	——— ?		
Palæozoic.	Carboniferous.	Late	For all.
	Devonian.	Mid.	
	Silurian.	Early.	
	Ordovician.		
	Cambrian.		
Proterozoic	Keweenawan		
	Huronian?		
	Laurentian ? or new name.		
Azoic	Archæan.		

For purposes of instruction the provincial scheme for rocks for the special region studied may serve as a standard.

It is desirable to adhere to European standards, or the present American standards as derived from Europe, as closely as possible until our present knowledge expands sufficiently to enable us to gradually erect new and more rational standards. The first and second orders should be as closely equivalent as

possible, and with the same names for both continents, and for the whole world. It is better to have everywhere the same terminology with approximate parallelism in meaning than different names and no means of unconscious comparison.

At the present time no series are formally recognized in the Devonian. The system is doubtless as well differentiated in this respect as the Carboniferous.

It is exceedingly doubtful whether the term Permian should be permitted to hold a place in American geological literature or classification. The original Permian is perhaps applied to a provincial series, taxonomically of the same rank as Mississippian. In America the so-called Permian is also a series and actually a subdivision of the Carboniferous. The same is true of the so-called sub-Carboniferous. It follows that neither should be coördinated with the Devonian.

The use of the term sub-Carboniferous in American geology is very unfortunate. As originally proposed, and as used for a long time afterwards, it referred to an indefinite sequence of strata extending downward from the "Coal Measures" even as far as the Trenton. As more recently used the subdivision so called would be better designated the Lower Carboniferous, the serial rank being understood, Mississippian being regarded as the equivalent provincial title as explained above. Neither Carboniferous nor any other unqualified term should be used for both system and series, or any two subdivisions of different taxonomic rank.

Canadian seems wholly out of place in the sense used unless it can be modified so as to denote a series. The use of Trenton in two different senses should be discontinued. It appears unnecessary to retain the word river in connection with Hudson —even though it has been widely used. And similar double geographic names are to be avoided.

CONTRIBUTION OF SAMUEL CALVIN.

Referring to your inquiries relative to the classification of time and terranes best adapted to North American geology, I

would say that I am disposed to be very conservative and would like to see as little disturbance as possible of terms that have met with somewhat general acceptance. The terms, *Group*, *System*, *Series*, *Stage*, and the correlative time-divisions, *Era*, *Period*, *Epoch*, *Age*, are to my mind very satisfactory. Of course any other terms would answer equally well provided geologists were agreed to use them. What we need to do, as it seems to me, is to adopt in this case the method that is in most general use, and by extending the use of it to make it more and more general until it becomes universally adopted. I would not like to see the term *Formation* used in place of *Stage*, and this simply for the reason that *Formation* is now in use as a loose, general term. Such a term is very much needed, and any attempt to change *Formation* from a loose to a precise term would be attended with great confusion. Heaven knows we have confusion enough now to contend with.

It does not seem to me to do any harm to leave the Lower Carboniferous or Mississippian as a division of the Carboniferous. The use of the term Mississippian would be an advantage; and the arrangement I would prefer, simply as a result of my attitude of conservatism, would give Mississippian the same rank as Corniferous, Hamilton and Chemung in the stratigraphy of the Devonian.

The greater part of the assemblage of strata called Permian by Prosser and the geologists of Kansas University contains precisely the same fauna as our Missourian or Upper Coal Measures, and if there is no better excuse for recognizing Permian in America than that afforded by the beds in question, then America has no Permian. At all events if these strata are Permian then the Permian cannot be separated from the Carboniferous. A large percentage of the so-called Permian fauna occurs in the coal-bearing strata of Indiana, Illinois and Iowa, that is, the fauna actually begins in what we call in Iowa the Des Moines stage, or Lower Coal Measures. Personally I see no good reason for recognizing Permian in America, but if we must in order to keep up with Europe, then the Permian must rank as a subdivision of

the Carboniferous. We might therefore arrange the Carboniferous in some such way as this :

Carboniferous	Permian.		
	Pennsylvanian or Coal Measures	Missourian.	
		Des Moines.	
	Mississippian or Lower Carboniferous	Kaskaskia.	
		Saint Louis.	
		Osage or Augusta.	
		Kinderhook.	

9. I would prefer to leave the Cretaceous undivided, being governed in this choice simply by the conservative desire to leave things undisturbed. The literature of the Mesozoic is based on the division into the Triassic, Jurassic and Cretaceous, and any change will require a long period of adjustment and will involve endless confusion. It is much easier, and just as convenient to let the Cretaceous stand as a single system and divide it into a Lower (Comanche ?) and an Upper (unnamed) series.

Cretaceous System.	Upper Cretaceous (Black Hills series)	Denver.	
		Laramie.	
		Montana.	
		Colorado.	
		Dakota.	
	Lower Cretaceous (Comanche series)	Washita	or any other arrangement.
		Fredericksburg	
		Trinity	

The whole of the Upper Cretaceous, excepting the Laramie and Denver, is well developed around the flanks of the Black Hills.

We can retain the established names in the Cenozoic and adapt our nomenclature with perfect ease to the old arrangement

by adopting appropriate stage names. We shall here need two sets of stage names, one for the marine Tertiary and the other for the fresh-water Tertiary deposits.

Cenozoic Group	Pleistocene	Recent.
		Glacial.
	Tertiary	Pliocene.
		Miocene.
		Eocene.

12. There is some advantage in retaining the terms Canadian and Trenton as names of series in the Ordovician. The faunas of the Trenton limestone, the Utica and Hudson River shales are very intimately related, and that relation should be indicated by grouping the three together as stages of a single series. The Calciferous and Chazy should similarly be grouped into one series.

I believe if you have patience to read all this that you will see how I would stand with reference to the several questions in your circular letter. Any classification is arbitrary at best. A dozen or more equally good schemes might be proposed, but we should adopt and strengthen as far as possible that which is in most general use, notwithstanding the fact that it might be improved in many respects. SAMUEL CALVIN.

PROBABLE STRATIGRAPHICAL EQUIVALENTS OF THE COAL MEASURES OF ARKANSAS.

One of the most striking features connected with the coal field of the western interior basin is the enormous thickness which the productive Coal Measures appear to attain in the southern part of the area as compared with the northern and larger portion. From the Minnesota line, southward through Iowa and Missouri, to northwestern Arkansas—a distance of more than 500 miles—the principal coal-bearing series retains a thickness of not more than 500 to 600 feet. Cretaceous and Tertiary beveling and planing, as well as later erosion, have of course thinned out the beds to a feather-edge towards the east. Passing into Arkansas the formation rapidly becomes thicker until it has a vertical measurement of more than thrice that to the north. According to Branner's[1] latest estimate the "Coal Measures" of that region are over 2400 feet thick.

In the various comments upon this great thickness which the Carboniferous rocks above the Mississippian series at once assume on passing to the south side of the Boston mountains, into the Arkansas valley, no hint has been given as to the probable conditions that produced such a remarkable phenomenon.

One thing that has tended to greatly obscure the real facts has been the assumption that the old Algonkian and old Cambrian or Silurian areas of the Ozark region formed, during all Palæozoic times, a large island in the shallow continental sea. The evidence, as recently set forth, seems indisputable that not only did no "Ozark Isle" exist during late Palæozoic time, but that the present dome-shaped, island-like character of the region, with the central old rocks, and the concentric belts of newer deposits around, was not acquired until Tertiary times. Furthermore, there is every reason to believe that the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

strata once extended unbrokenly over the whole area now occupied by the uplift, and that they were removed through erosion.

As already remarked the great thickening of the Coal Measures begins to make itself apparent immediately south of the Boston mountains; north of this range the stratigraphy has been more or less clearly understood. The two main subdivisions are clearly defined over all of the northern region. There they represent a lower, or coastal facies and an upper, or marine phase. The plane separating them is the base of the first thick limestone above the Mississippian series. This formation is now called the Bethany limestone. It is a marked and persistent feature of surface relief from north-central Iowa, where it emerges from beneath the Cretaceous, southward through northwestern Missouri, and southeastern Kansas, to the Indian Territory line, beyond which it has not been traced in detail, although at that point it still continues to be an important and easily recognizable ridge.[1]

Regarding the southern part of the coal field much has been written, but it has only been very lately that definite data have been given, that enables comparisons with the northern districts to be made. The facts recently published have a special importance at this time for the reason that they strongly support certain views concerning the physical conditions, the existence of which have been, for some time, suspected, and enable several statements to be formulated regarding the character of Carboniferous deposition in the region. The data particularly referred to are contained in a paper by J. P. Smith[2] on the "Marine Fossils from the Coal Measures of Arkansas." While the facts therein presented are not nearly as complete as is to be desired, they nevertheless appear sufficient, when taken in connection with information derived from other sources, to permit several pregnant deductions to be made.

One of the most noticeable features of the Carboniferous

[1] Am. Jour. Sci., (4), Vol. II, pp. 222–225, 1896.

[2] Proc. American Philos. Soc., Vol. XXXV, pp. 213–285, 1896.

deposits of Arkansas, and especially those of the western part of the state, is the prevalence of sandstones and shales above the strata of the Augusta stage (Boone chert) of the Mississippian. There are, however, in the region occupied by the Boston mountains, two limestones of unusual thickness which lie at levels considerably above the Augusta beds. These have been called[1] the Archimedes and Pentremital limestones. They are separated from each other by 40 to 75 feet of shale. The interval between the first mentioned and the limestones beneath is about 200 feet and is occupied by shales and sandstones. The Pentremital limestone may be taken, with but little doubt, as corresponding to the Kaskaskia limestone of western Illinois. Its stratigraphical, lithological and faunal characters all agree in this respect.[2] There do not appear to be any indications of a plane of unconformity at the top of this heavy Pentremital formation, as there is at the summit of an equivalent stratum along the Mississippi River. The Arkansas sequence of the Carboniferous seems unbroken and undisturbed from base to top. The Pentremital limestone may be therefore regarded as the uppermost member of the Mississippian of the region, and the overlying coal-bearing shales as the basal portion of the Coal Measures, or Des Moines series, of the more northern localities.

In regard to the upper limits of the Arkansas valley Coal Measures, or of any definitely determinable horizon in the great succession, there are not yet at hand any very critical data. The lately issued notes of Smith[3] on the fossils collected in the region by the members of the Arkansas Geological Survey give the first tangible facts that have been obtained, and by which any comparison whatever can be made with the better known region north of the Boston mountains.

All who have worked in the Arkansas valley agree in assigning a very great thickness to the Coal Measures of that region. This is readily inferred from the writings of Chance,[4]

[1] SIMONDS, Arkansas Geol. Surv., Ann. Rept. 1888, Vol. II, p. 26, 1891.

[2] American Geologist, Vol. XVI, pp. 86–91, 1895. [3] Loc. cit.

[4] Trans. American Inst. Min. Eng., Vol. XVIII, pp. 653–661, 1890.

Winslow,[1] Stevenson,[2] Branner[3] and others. While the total thickness of the Coal Measures is doubtless somewhat overestimated by these authors, it is manifest that the formation is very thick—several times as great as it is farther northward.

The subdivisions of the Arkansas Coal Measures that have been recognized have not always been the same. In several instances they have been quite different. The classifications have been either noncommittal as to exact correlation with other regions, or they have been very general. The members distinguished have been largely for convenience in local field work. The tendency has been, however, to regard the Coal Measures of this region as about equivalent to the Coal Measures ("upper and lower divisions") of other districts north and east, with the intimation, in the later notes, that the so-called Permian of the western part of the Mississippi basin, may be present to some extent, as for example on Poteau mountain. In the latest contribution to the subject by Smith,[4] the "Upper Coal Measures" and the "Lower Coal Measures" of the Arkansas valley are paralleled with the similarly named formations of the Missouri region. The Poteau mountain beds are included. The conclusion is that "there is not sufficient reason for classing the Poteau mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi valley Upper Coal Measures. These beds derive an additional interest from the fact that on Poteau mountain 1000 feet of shale, in which no fossils were sought for, lie above the thin layer from which the entire collection was taken; thus the chance of finding true Permian beds in that region are very good." From this it will be seen at once that the Arkansas section is regarded as representing the Des Moines and Missourian series of Missouri and Kansas, as embraced between the Mississippian limestones

[1] Bull. Geol. Soc. America, Vol. II, pp. 225-242, 1891.

[2] Trans. New York Acad. Sci., Vol. XV, pp. 50–61, 1895.

[3] Am. Jour. Sci., (4), Vol. II, p. 235, 1896.

[4] Loc. cit.

and the Cottonwood limestone of the central part of the last mentioned state.

A careful comparison of the species of fossils that are considered by Smith from the "Upper Coal Measures" with those from the Upper and Lower Coal Measures of other parts of the Western Interior basin brings out the fact that the Arkansas fauna not only does not necessarily indicate a "very high" position in the Upper Coal Measures of the zone containing it, but that it may be, and probably is, very low. Judging from the fauna alone, and as a whole, according to the palæontological standard of its nearest and most closely related districts—the Missouri-Kansas province, with which it is properly compared—the indications are that the age of the strata yielding it is not that of the "Upper Coal Measures" at all, but of the "lower division"—that is, of the Des Moines series of the more northern localities.

All of the Arkansas species, with very few exceptions, are, in Iowa, Missouri and Kansas, the most widely distributed forms. Most of them range from the base to the top of the Des Moines series, and continue on upwards. In the lower series the marine beds are almost wholly absent, only a few thin limestones being present in the whole succession. Nevertheless the same species that are found in Arkansas occur abundantly not only in the thin limestone layers, which are rarely more than a few inches in thickness, but also in the calcareous shales, and, in less numbers even in the bituminous shales.

Of the corals listed from Arkansas only one form has a range that is unusually "high" in the northern succession; all of the others start almost from the very base of the series. The crinoids and bryozoans are all common in the Lower Coal Measures. All fourteen species of brachiopods are of very frequent occurence in the lower coal division, many commencing down in the Mississippian. One possible exception is *Terebratula bovidens*, which at present appears to be absent from some of the lower Des Moines beds. Of the lamellibranchs, all twenty-two species are the most characteristic forms of the very base

of the Missourian; one-half of the number are found lower down, and no less than seven are typical Des Moines forms, in fact having an *optimum habitat* not in the marine beds but in the bituminous shales. The seven species of glossophora that are enumerated are the most abundant forms of the Lower Coal Measures throughout the northern district, and they are pre-eminently the characteristic fossils of the black shales everywhere. Among the ten cephalopods named, no less than five are of common occurrence in the Des Moines beds, and not infrequently they are found in the black shales; the other five, so far as known, range low in the Missourian.

If the faunal evidence, as recently presented, is to be relied upon at all, it would appear that there are no grounds for believing that there are necessarily present in the deposits of the Arkansas valley region any strata higher than the base of the Missourian series of Missouri and Kansas.

There is, however, another reason for believing that no part of the Missourian series, or its equivalent, exists in Arkansas. The general stratigraphy as far as it is now understood, gives not only no indication of the Missourian beds being represented in the region, but points almost conclusively to their absence.

The broad belt of lowland, lying below the contour of 1000 feet, and between the Ozark uplift and the elevated region of the Great Plains, extends from the Missouri river southwestwardly into Indian Territory and then eastwardly through the Arkansas valley to the savannas of the Mississippi embayment. This lowland is occupied chiefly by shales which have relatively much less resistant powers to erosion than the limestones on either side of the belt. In Missouri the subdivisions of the Coal Measures, both "Upper" and "Lower," have been clearly made out. In Kansas Haworth[1] has traced the same divisions to the Indian Territory line, so that down to the juncture of the great lowland valley and that of the Arkansas, the surface distribution of the several formations of

[1] Univ. Geol. Surv. Kansas, Vol. I, 1896.

the Carboniferous is well known. In Indian Territory the information is not yet as full as would be desirable. Still there are enough facts at hand to indicate the general features of the main subdivisions, or series. The Missourian, or more strictly marine series, composed of important limestones, does not appear to extend down the Arkansas valley into Arkansas, nor to change very much in lithological character. The Pawhuski limestone in eastern Oklahoma, regarded by Smith[1] as representing the same horizon of "Upper Coal Measures" farther east, certainly cannot be stratigraphically equivalent to any part of the Coal Measures that exist in the same latitude in Indian Territory. While it is not yet known with certainty just what its exact equivalent is, it is quite probable that it is the southern extension of what is termed the Iola limestone in the region to the north. If this is the case, the position of the limestone exposed in the quarries at Pawhuski is very near the base of the Missourian, or "Upper Coal Measures."

If, as now appears probable, the enormously thick Coal Measures of the Arkansas valley are practically the exact equivalents of only the lower division, or the Des Moines series of the region farther north, instead of representing the entire interval between the Mississippian and the so-called Permian (Oklahoman), or that part of the Carboniferous above the Cottonwood limestone in Kansas and Oklahoma, the explanation of the great increase in the thickness southward, would seem still more difficult. There have been, however, a number of new facts recently brought out regarding the diastatic changes that have taken place in the Ozark region, and some of these have a direct bearing upon the question under consideration.

It has been lately shown[2] that during the Kaskaskia, or closing epoch of early Carboniferous times in the Mississippi valley, there was a series of rapid changes in the relations of land and sea. At the beginning of the Kaskaskia the shore line had moved southward 400 to 500 miles at least from the

[1] Proc. Amer. Philos. Soc., Vol. XXXV, p. 230, 1896.

[2] Bull. Geol. Soc. America, Vol. III, p. 296, 1892.

latitude it occupied during the St. Louis, or approximately to the latitude of the present mouth of the Missouri River. This permitted erosion of the land surface north of this point; and immediately south of it the disposition of coarse sediments, covering the other marine beds of the Mississippian. Marine deposits of the later Kaskaskia, were again laid down over the coastal deposits of the same region. With a further recession of the sea some of the territory occupied by Kaskaskia rocks was also made land and was subjected to erosion. According to the recent suggestions of Marbut[1] the shore line at this time, when it had traveled farthest to the southward, coincided very nearly with the present crest of the Ozark uplift, that extends along a line drawn from Iron Mountain to the southwest corner of the state of Missouri.

It is now a well-established fact that everywhere to the north of the present Ozark crest profound erosion took place between the time when the St. Louis limestone was deposited and that when the Coal Measures were formed. Moreover, the effect of this land degradation must have left the country very much in the condition of a peneplane, for the old land surface is a rather even one, with no marked contrasts of relief. It beveled the previously slightly tilted strata, for the Coal Measures rest on the rocks of all ages from the Silurian to the top of the Lower Carboniferous. This stratigraphic hiatus, represented by the plane of unconformity at the base of the northern Coal Measures, manifestly indicates an episode in the physical history of the region, the importance of which has been heretofore little appreciated.

In the southerly retreat of the sea during the close of Lower Carboniferous time, there was, of course, a point beyond which the shore line did not advance. Beyond this point, seawardly, deposition went on uninterruptedly, the succession of beds was continuous, and the layers were conformable throughout the Carboniferous system. Such conditions appear to have prevailed in the region of southern Missouri and northern

[1] Missouri Geol. Surv., Vol. X, p. 82, 1896.

Arkansas. South of the Ozark crest, if the inferences already drawn are to be relied upon, deposition was continuous, not only through the Lower Carboniferous period, but also during the

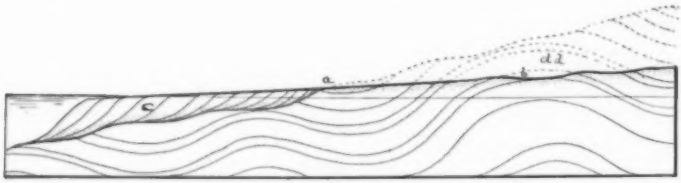

FIG. 1.—Ideal Conditions of Sedimentation.

interval when the region farther north was a land surface being rapidly eroded. As shown elsewhere,[1] the present Ozark dome had, of course, not begun to bow up. It was not a large island during the Carboniferous, as has been generally regarded. The

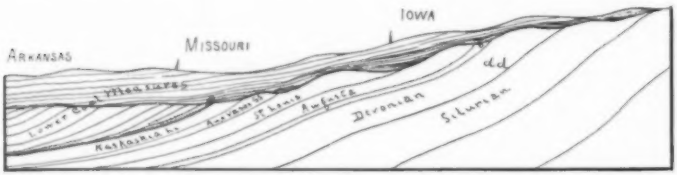

FIG. 2.—Cross Section of Mississippi Basin—Minnesota to Arkansas.

products of land degradation were, without doubt, dumped into the adjoining seas, just as the sediments of the present continent are being carried into the ocean to form the thick fringe of coarse shore deposits.

In general, the deposition of coarse sediments along the coast must have been represented by degradation on land. This phenomenon may be shown by the subjoined sketch (Fig. 1), in which *a* is the original shore line; *b*, the land surface; *c*, the sediments removed and transported from the eroded parts of the strata *d*, *d*, which had been subjected to deformation since their formation. Identically the same conditions obtained in the case

[1] Missouri Geol. Surv., Vol. VIII, p. 352, 1895.

of the Carboniferous deposits of the Continental Interior. It is also representative of the conditions existing at the present day on the Gulf coast, and is typical of sedimentation generally.

A diagrammatic cross-section, north and south, from Minnesota to central Arkansas, and representing the relations of the Carboniferous deposits of the region, is given in Fig. 2.

The true marine beds of the Missourian series, or "Upper Coal Measures," may have extended, and probably did stretch out over a considerable part, and possibly all, of the region; but erosion, since Carboniferous times, has removed all traces of these deposits.

CHARLES R. KEYES.

ON THE ORIGIN OF CERTAIN SILICEOUS ROCKS.

I. NOTES ON ARKANSAS NOVACULITE.

An examination of the residues of specimens representing both the Ouachita and Arkansas (commercial) types of novaculite confirms Griswold's observations and conclusions made on thin sections. Ground in an agate or porcelain mortar, the greater part of the rock is easily reduced to a fine slime that readily floats away in water. A considerable portion, however, consists of granules which, though made up of fine grains, require considerable rubbing to reduce them to slime. Even when, in the final stages of the grinding, a soft pestle is employed to avoid breaking up the grains of quartz and other minerals, a considerable number of the aggregated granules remain, thus showing a strong cohesion of the constituent grains.

The amount of quartz in simple grains that can be positively identified by the polarization colors is not large, and for the most part is not distinctly detrital. Such grains are frequently enclosed in the composite ones or have composite silica adhering to them, and often appear to be more completely developed individuals of the aggregated grains. In many cases, however, they appear to be detrital grains with adherent secondary silica. Unmistakable detrital grains are represented by numerous zircons and rare fragments of tourmaline and garnet.[1] These are exceedingly fine, and both in character and amount seem to confirm Griswold's conclusion that the deposit took place in still and comparatively deep water into which only a small amount of very fine detritus would be floated.

The great bulk of the silica of these rocks appears to be secondary, and to account for its peculiarities the replacement hypothesis of Rutley seems to offer less difficulty than that of

[1] Wichmann found garnets in the novaculites of the Marquette, Mich., district in 1879. Q. J. Geol Soc., Vol. XXXV, 1879, pp. 156–164, J. C. Branner.

an originally siliceous sediment of Griswold. The latter must either have been chemical, which Griswold expressly rejects, and apparently very properly, or composed of very fine granular quartz. In the latter case the granules, however fine, have been still further granulated, a species of metamorphism which has apparently not been observed elsewhere, and which is difficult to conceive. The metamorphism, if there had been any, would rather be expected to be in the direction of larger and well-defined grains of quartz, such as were noted in some of Griswold's slides (No. 14).[1] The latter slide seems to be a case of replacement according to Rutley's hypothesis "caught in the act." It may be suspected that in a larger suite, especially of non-commercial stones, other such cases might be found.

Griswold's explanation of the cavities seems also to point in the direction of a replacement, and can be reconciled with Rutley's hypothesis on the supposition, which does not seem difficult, that part of the original calcareous sediment may have crystallized (not necessarily as dolomite) and thus have offered greater resistance to the replacement.

The description of the beds also is suggestive of original limestones with cherty layers and nodules. Two of the specimens sent appear to me to represent such cherts, though I should not call them metamorphosed.

The question of the state of the silica seems to me to be one of quite secondary importance, as in the case of silicified wood replacement silica is met with in all states, and often with an appearance of a passage to the state of quartz after the replacement.

Viewing the question from a distance, and on a very insufficient basis, it seems probable that if Mr. Griswold had taken into consideration the hypothesis of a replacement of calcareous sediments, he would, perhaps, have found much more in its favor than either Rutley or I could see.

For the study of crucial points, "non-commercial" rock will

[1] Whetstones and the Novaculites of Arkansas. By L. S. GRISWOLD. Ann. Rep. Geol. Surv. Ark. for 1890, III, p. 128.

probably be often better than the "commercial," and the preparation and examination of residues more rapid and satisfactory than that of microscopic sections.

ORVILLE A. DERBY.

SÃO PAULO, Brazil, April 6, 1898.

II. ON THE ORIGIN OF NOVACULITES AND RELATED ROCKS.

The preceding part of this paper was recently received by me from Professor O. A. Derby as embodying the results of his examination of novaculites by a method hitherto not employed with those rocks. It should be added that in a former letter he sent me the results of a study by this same method of an impure cherty Carboniferous limestone from Tieté, São Paulo. In this limestone he found by crushing and washing, rolled quartz, zircon, rutile, garnet, tourmaline, etc.

These notes I have taken the liberty to publish without consulting Professor Derby in order that the results of his work may become available for others who may study this interesting and important group of rocks.

It is remarkable that so many different views have been held regarding the origin of novaculites and of the closely related highly siliceous rocks known as jaspilites and sometimes as jaspers, siliceous shales, etc.

The following theories have been advanced to explain the origin of these rocks:

Foster and Whitney seem to have regarded the jaspers of Michigan[1] as segregations of eruptive origin. Owen considered the Arkansas novaculites as metamorphosed sandstone.[2]

Kimball believed the Marquette iron ores and their associated jaspers to be metamorphic rocks of sedimentary origin, presumably mechanical.[3]

[1] Geology and Topography of the Lake Superior Land District. Pt. II. The Iron Region, pp. 67–69, 1851.

[2] Second Geol. Surv. Ark., pp. 23, 25, 1860.

[3] Am. Jour. Sci., Vol. XXXIX, p. 303, 1865.

Crosby thinks some of the jaspers and quartzites are the siliceous oozes of the deep sea, that is, that they are of organic origin.[1]

Wadsworth at first believed in an eruptive origin for the jaspilites.[2] This view he modified later.

Julien believes in the mechanical sedimentary origin of the jasper iron ores of the Marquette region, and it is to be presumed that he considers the jaspers mechanical sediments also.[3]

Irving concluded that the jaspers were formed by silica replacing dolomite or calcite.[4]

Reyer thinks the sediments associated with the iron ores of Michigan are derived partly from decomposed igneous rocks and partly from organic remains.[5]

Branner has suggested that the compact novaculites may be metamorphosed cherts.[6]

Comstock considered many of the Arkansas novaculites to be hot water deposits.[7]

Julien thinks amorphous silica is produced by marine organisms, or by precipitation from solutions.[8]

Griswold is of the opinion that novaculites are simply metamorphosed, fine grained, mechanical sediments.[9]

N. H. and H. V. Winchell believe in the theory of chemical precipitation for the jaspilites.[10]

James E. Mills is of the opinion that certain quartzites of the

[1] Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 167–168, 1878–1880.

[2] Bull. Mus. Comp. Zool., Vol. VII, p. 30, 1880; Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 477–478, 1878–1880; Bull. Mus. Comp. Zool. Harvard Col., Geol. Ser. I, Vol. XVI, pp. 331–565, 1884.

[3] Genesis of the Crystalline Iron Ores. By A. A. JULIEN. Eng. Mining Jour., Vol. XXVII, pp. 81–83, 1884.

[4] Am. Jour. Sci., Vol. XXXII, p. 255, 1886.

[5] Geologie der amerikanischen Eisenlagerstätten. E. REYER. Oest. Zeitsch. f. Berg. u. Huttenwesen, XXXV, Nos. 10 and 11, 1887.

[6] Ann. Rep. Geol. Surv. Ark., Vol. I, p. 49, footnote, 1888.

[7] Ann. Rep. Geol. Surv. Ark., Vol. I, pp. 95, 129, 1888.

[8] Proc. A. A. A. S., Vol. XXVII, pp. 311–340, 1889.

[9] Ann. Rep. Geol. Surv. Ark., Vol. III, pp. 164, 194, 1890.

[10] The Iron Ores of Minnesota. By N. H. and H. V. WINCHELL. Minneapolis, 1891, p. 74.

Sierras, in California, are replacements of clays by silica,[1] and that others are possibly replacements of limestone by silica.

Wadsworth came to believe in their sedimentary origin.[2]

Rutley in a review of the subject reached the conclusion that the novaculites were replacements by silica of dolomites or of dolomitic limestones.[3]

Hinde expressed the opinion on the occasion of the reading of Rutley's paper that these rocks were of organic origin.[4]

Lawson thinks the "radiolarian cherts," that is, the jaspers of the coast ranges of California, are local deposits chemically precipitated from submarine siliceous springs.[5]

Branner thinks the jaspers are of organic origin.[6]

Van Hise in speaking of certain jaspers of the Marquette district says: "It appears highly probable that dynamic action transformed the ferruginous chert into the jasper."[7]

Derby's views, that novaculites are replacements of limestones by silica, are given in the first part of the present paper.

Fairbanks has concluded that the Tertiary siliceous shales of the coast ranges of California are derived from diatomaceous beds.[8]

Doubtless many other expressions of views regarding the origin of these siliceous rocks might readily be found, but these are enough to show that there has been the widest possible difference of opinions on the subject.

We have then the following theories, that the novaculites, jaspilites, jaspers, etc., are:

1. Mechanical silts.
2. Organic silts.

[1] Bull. Geol. Soc. Am., Vol. III, pp. 421–422, 440, 1892.

[2] M. E. WADSWORTH, Rep. State Geol. for 1891–2. State Board of Geol. Surv. (of Michigan) for 1891–2. Lansing, 1893, pp. 75–155, dated March 1892.

[3] Quart. Jour. Geol. Soc., Vol. L, p. 386, 1894.

[4] Quart. Jour. Geol. Soc., Vol. L, p. 391–392, 1894.

[5] 15th Ann. Rep. U. S. G. S., pp. 425–426, 1895.

[6] Trans. Amer. Soc. C. E., Vol. XXXIX, p. 58. Read Nov. 17, 1897.

[7] Monog. U. S. G. S., Vol. XXVIII, p. 372, 1897.

[8] San Luis Obispo folio, U. S. G. S. (MSS.).

3. Chemical precipitates.
4. Igneous deposits.
5. Replacements of clays.
6. Replacements of limestones.
7. Replacements of dolomites.

The most comprehensive discussions of this subject are those of Griswold and of Rutley. But these writers do not agree in regard to the origin of the rocks, the former believing them to be fine sediments, the latter believing them to be replacements of dolomites or limestones.

My own opinions have not been based upon such microscopic study as either Griswold or Rutley devoted to this work, and for that reason were not worthy of special consideration. Since I began to study the geology of the coast ranges of California, however, I have, I believe, seen much that throws light upon the origin of the novaculites and similar rocks.

These observations embrace those upon geological structure, gross and microscopic structure, composition and geological relations, and lead me to believe that the white siliceous shales so characteristic of the Tertiary, the jaspers and the diatomaceous beds are only various phases of the same thing.

I am glad to say that Dr. H. W. Fairbanks, whose acquaintance with the coast range geology makes his opinion especially valuable, expresses similar views on this subject. Dr. Fairbanks, however, has undertaken a thorough study of this subject from which important results may be expected.

J. C. BRANNER.

STANFORD UNIVERSITY, CALIFORNIA.
June 4, 1898.

A STUDY OF SOME EXAMPLES OF ROCK VARIATION.[1]

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In the following article I purpose to describe briefly a series of igneous rocks which vary from those of acid character through those of intermediate and basic characters to others which are ultrabasic in composition. The rocks occur upon the upper peninsula of Michigan, in the vicinity of Crystal Falls, the most important town in the iron-bearing district of the same name. All are to be found in an area extending from Crystal Falls southeast to a mile east of the Michigamme River. In the description of the various kinds no detailed mention of localities will be given, since they are given in the complete article, and if wanted can readily be found by reference to it. The rocks occur as knobs or groups of knobs, and as well determinable dikes cutting the knobs. The outcrops project through an area covered by glacial deposits. The best exposures are naturally near the river, where erosion has removed the drift mantle.

Here and there in the drift are isolated exposures of sedimentary rocks of Upper Huronian age. The relations of the igneous rocks to the sedimentaries are not shown by exposures of direct contacts, but it is inferred from the occurrence of sedimentaries between the igneous exposures that the drift is underlain by Upper Huronian sedimentaries, and that the igneous rocks are intrusive in them. The intrusives have never been found to penetrate the superimposed, horizontal, Lake Superior, Potsdam sandstone. These facts are conclusive proof that their period of

[1] This article is a brief abstract of a part of a report which will appear in full as a monograph of the U. S. Geol. Surv., under the title of "The Crystal Falls Iron-bearing District of Michigan." For details which are not warranted in this place the reader is referred to the monograph. An abstract of the monograph, in which the portion treated in the present article is barely mentioned on account of lack of space, will be published under the same title as the monograph in the 19th Annual Report.

intrusion fell in the time between the deposits of the Upper Huronian and those of the Cambrian. In the complete article there is a discussion of the time of the folding of the Upper Huronian, and the conclusion is reached that this folding took place immediately preceding the deposit of the Keweenawan series. If these intrusives had existed at that time, they must certainly have suffered from the orogenic movements. Examination of the exposures of the intrusives has not shown schistose masses, nor has detailed microscopical study disclosed any textures which accompany powerful dynamic movements, except in isolated cases which are presumed to be due to purely local movements. Such being the case, the conclusion follows that these intrusives are subsequent in their origin to the folding of the Upper Huronian; that is, are of Keweenawan or of post-Keweenawan age.

It seems highly probable, though it cannot now be proven, that the intrusives are contemporaneous with the period of volcanic activity, during which the heterogenous Keweenawan series was formed. During the formation of such a great series we might well expect more or less fissuring of the sedimentaries and intrusion of molten magma in a district no farther removed from the scene of eruptive activity than is the Crystal Falls district from the Keweenawan, a distance of about thirty miles. It is at least clear that the rocks are post-Huronian and pre-Potsdam, but a closer approximation cannot be made with certainty.

With few exceptions the intrusive rocks are medium to coarse-grained. While the granitic texture is unquestionably predominant, other textures are not absent, for we find some ophitic and porphyritic textured rocks, and others in which even a parallel (flow) texture has been produced. It has already been intimated that the chemical range is very great. There is, of course, a corresponding range in color.

The main classes with which the variations will be grouped are the diorites, the gabbros, or gabbro-norites, and the peridotites. Complete and accurate chemical analyses of certain

rocks of these chief classes have been obtained and the microscopical diagnosis thereby confirmed. Within each of these main divisions well marked varieties can be distinguished. While between the gabbros and the peridotites a transition is unquestionable, a less positive statement must be made for the connection between the diorites and the gabbros, and while the writer is convinced that such connection exists, he is aware that the reader may not take the same position. In the following pages the three main classes will be briefly described, and then the variations within each class. The relations between the various main divisions will be described, and then, with a brief summary of the facts, the reader will be enabled to draw his own conclusions.

Diorites.—Following Brögger's definition,[1] the name diorite is in the following pages restricted to granitic textured plutonic rocks of intermediate acidity, consisting essentially of plagioclase and either primary hornblende, pyroxene, or mica, or two or more of these.

This is very different from the usage by a number of the previous writers on the Lake Superior region, who called the uralitized dolerites "diorites" or "epidiorites." As a result of the introduction of the use of this name diorite by scientific men, it is now in common use among the miners in the Lake Superior iron regions, and is usually applied by them to any greenish rock whose sedimentary characters are not clearly recognized, very much in the same way that the field geologist uses greenstone, especially if the green rock is associated with an iron formation. In the great majority of cases such rocks are dolerites in a more or less advanced stage of alteration, and rarely, if at all, pure diorites.

The dioritic rocks are of medium to coarse grain. In texture they show some variations from rocks of a granitic texture

[1] Die Eruptivgesteine des Kristianiagebietes, by W. C. Brögger in Videnskabsselskabets Skrifter, I Mathematisk- naturv. Klasse. Pt. I, Die Gesteine der Grorudit-Tinguait-Serie, 1894, No. 4, p. 93. Pt. II, Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, No. 7, p. 35.

to others which incline to the ophitic texture, and to still others which are distinctly micropegmatitic. The granitic texture is the most frequent. The color is uniformly light gray or reddish, but at times, when the ferromagnesian minerals are present in greater quantity, they become dark gray or greenish brown.

The important mineral constituents are feldspar, quartz, hornblende, and biotite. Apatite, zircon, sphene, iron oxide, and epidote (?) are the accessory minerals. The secondary minerals present are white and brown mica, chlorite, epidote, zoisite, calcite, and rutile. Plagioclase feldspar, orthoclase, and microcline occur together. The plagioclase is present in individuals which are fairly automorphic. In the ophitic textured diorites, the plagioclase is the best developed of any of the essential constituents. In the granitic textured rocks the degree of automorphism is highest where orthoclase and quartz are present in the largest quantity, and diminish as these diminish in consequence of the interference of the plagioclase individuals. For the most part the plagioclases yield rather narrow sections, though they can hardly be called lath-shaped. Measurements show the plagioclase to be andesine. It is very much altered. Orthoclase is present in large plates, which form a part of the mesostasis for the plagioclase and the bisilicates. The quantity of orthoclase varies considerably. It is very much decomposed. Microcline is not abundant. It is very fresh, and in many cases automorphic with respect to the orthoclase and quartz. Quartz is present in variable quantity, and with the orthoclase forms the mesostasis. The hornblende shows a good development in the prismatic zone. The terminal planes are not so well developed. It varies from dirty green to reddish-brown in color. The reddish-brown variety occurs in the center of the crystals and is surrounded by the green. The differently colored zones thus produced are not sharply delimited, and are also in perfect optical continuity. No evidence is found indicating the green kind to be an alteration product from the brown variety, and they are both assumed to be primary. The biotite is brown,

and shows its usual characters. It is less well developed than the hornblende. All of the other minerals show their usual well-known characters.

According to the variations in the proportions of the essential minerals, plagioclase, orthoclase, quartz, hornblende, and biotite, we get the following varieties of diorite: quartz-diorite, tonalite, quartz-mica-diorite, and mica-diorite. This variation is best shown in a connected group of knobs composed of medium grained rock, which varies in color from light pink to a very dark greenish-gray. Areas of light and dark colored rock may be seen extending in finger-like projections into one another. There are no sharp boundaries between them, however, but, on the contrary, a gradual passage from the light to the dark variety. Some of the rocks also contain small, more or less rounded areas, which are clearly segregations of ferromagnesian minerals. These different phases evidently belong to a single rock mass, but the microscope enables a separation to be made into the several mineralogical and textural facies already mentioned. The main mass of the rock forming the knobs appears to be a tonalite which resembles the published description by Becke[1] of that from the Rieserferner. It also closely resembles some slides of the typical Adamello tonalite with which I have been able to compare it. This tonalite grades by diminution of biotite with corresponding increase of hornblende into quartz-diorite, and by a diminution or disappearance of the hornblende and increase of the biotite into a quartz-mica-diorite. Where the quartz of this last variety is practically wanting, we get a mica-diorite. In this small massif pure types of the rocks described are of rare occurrence. Orthoclase is present in all of these dioritic rocks. In certain facies the orthoclase and quartz are very abundant, and the plagioclase correspondingly subordinate. Such rocks approach closely the plagioclase-bearing granites.

The relationship to granites is better shown in a different

[1] Petrographische Studien am Tonalit der Rieserferner, by F. BECKE, Tsch. Mitt. Vol. XIII, 1892, pp. 379–464.

occurrence from the one just described, in which the greater portion of the rock is a plagioclase-bearing biotite-granite, showing in many cases most beautiful micropegmatitic texture, but with schlieren of a darker colored rock which might readily be called a quartz-mica-diorite. It is especially interesting to note also that this series of exposures is cut by a number of small dikes of uniform character, varying from fractions of an inch to three inches in width. The dike rock is very light gray to pink in color, and cryptocrystalline. Examined under the microscope, these dikes can be readily separated into a microporphyritic center, and a microgranitic textured selvage. Phenocrysts of quartz, feldspar, and biotite lie in a microgranitic groundmass of feldspar and quartz, between which occur secondary flakes of muscovite. The rock is a microporphyritic quartz-mica-diorite or quartz-mica-diorite-porphyry. This rock seems to bear a very strong resemblance to the tonalite-porphyrite described by Becke[1] which occurs as a dike facies of the Rieserferner tonalite to which I have already referred.

Still another illustration of the passage from the granitic to the dioritic rocks was observed upon a dike, four feet wide, which penetrates a knob of hornblende-gabbro. A specimen taken near the center of the dike discloses itself as a biotite-granite with a small amount of plagioclase. The sides of the dike consist of diorite, composed of andesine feldspar, and biotite, without any quartz. The sharp line of demarkation which exists between the dike and the gabbro seems to preclude the possibility of a fusion and mingling of the two rocks, such as has been suggested by Johnston-Lavis,[2] as in some cases causing variation in chemical composition of intrusive rocks, especially where this variation is one between the center and periphery of an intrusive mass. The diorite occurrences of the Crystal Falls district seem, in the gradations mentioned, to

[1] Loc. cit., pp. 434–441.

[2] The causes of variation in the composition of igneous rocks, by H. J. JOHNSTON-LAVIS: Natural Science, No. 4, pp. 134–146.

The basic eruptive rocks of Gran, Norway, and their interpretation, by H. J. JOHNSTON-LAVIS: Geol. Mag., 4th decade, Vol. I, 1894, p. 252.

be very similar to the tonalite from the Rieserferner described by Becke,[1] and also to the so-called grano-diorite massifs of California, described by Becker, Turner,[2] and Lindgren.[3] The grano-diorite of California appears from Lindgren's description to correspond very closely to tonalite, though Turner uses the name as synonymous with quartz-mica-diorite.

It has not been found possible thus far to obtain analyses of all these varieties. The more acid facies of the diorites seem to show very clearly their gradation towards tonalites and granites, and, from their content of free silica, the conclusion seems to be warranted that they are rather acid. Such being the case, it was deemed of more importance to study the relations of the less acid dioritic facies in order to determine their relationship with the basic gabbros and peridotites with which their connection is not so evident as it is with the granites. To this end a complete analysis was made by Dr. H. N. Stokes of a mica-diorite. The rock analyzed consists of biotite, hornblende, plagioclase, orthoclase, and quartz, with the biotite and plagioclase as the predominant characteristic constituents.

ANALYSIS OF MICA-DIORITE BY DR. N. H. STOKES.

SiO_2	58.51	MgO	3.73
TiO_2	.72	K_2O	4.08
Al_2O_3	16.32	Na_2O	3.11
Cr_2O_3	none	H_2O at 110°	.23
Fe_2O_3	2.11	H_2O above 110°	2.00
FeO	4.43	P_2O_5	.30
MnO	trace	CO_2	none
NiO	none		
CaO	3.92		99.46

Gabbros and norites.—The gabbros and norites are holocrystalline rocks of moderately fine to coarse grain. The rocks here included show a considerable variation in texture. Some

[1] Op. cit.

[2] Geology of the Sierra Nevada, by H. W. TURNER: 17th Ann. Rep. U. S. Geol. Surv., No. 1, 1896, pp. 636–724.

[3] Granitic rocks of California, by W. LINDGREN: Am. Jour. Sci., 4th series, Vol. III, 1897, p. 308. Here can be found reference to earlier articles on grano-diorites.

of the finest grained forms possess a very good parallel texture. Others are noticeably porphyritic. A few have a poikilitic texture. Less common is an approach to the ophitic texture of the dolerites. Most commonly of all, however, the rocks are granitic in texture. The color variation is not great, and is chiefly in dark brown or greenish-black tones. The important mineral constituents are feldspar, biotite, hornblende, pyroxene, and olivine. Apatite, sphene, zircon, rutile, octahedrite, brookite (?), and iron oxide occur as accessory minerals. White and brown mica, chlorite, hornblende, talc, serpentine, sphene, rutile, and calcite occur as secondary minerals.

Plagioclase and orthoclase-feldspar are both present. The last is, however, of doubtful occurrence. The plagioclase is labradorite, and shows its usual characters.

Hornblende is the most striking component in the majority of the sections. It is present in three different varieties, all of which occur in anhedra. The most prominent kind is a reddish-brown hornblende, which has a dark green hornblende commonly associated with it, and frequently in zonal intergrowth with it. This hornblende occurs without the green kind, but the green is invariably associated with the brown variety. The two are optically continuous in the intergrowth. It is possible, though not susceptible of proof, in the sections examined, that the green hornblende is the incipient alteration of the brown hornblende. The pleochroism is strong in the following colors:

Brown hornblende.

a	**b**	**c**
Light yellow or red, with tinge of green.	Reddish-brown.	Same as **b**, or else a darker reddish-brown. Exceptionally it is a light yellowish-brown.

c > b > > a

Green hornblende.

a	**b**	**c**
Greenish-yellow.	Yellowish or brownish-green.	Darker olive-green. Frequently with bluish tinge.

c > b > a

This hornblende, with respect to its rather exceptional pleochroism and its general characters, seems to agree very well with that described by van Horn[1] from very similar rocks from Italy, and like that is possibly very basic. The brown hornblende possesses a further interest in that it is frequently rendered very dark by the number of exceedingly small inclusions within it, and in this, and also in its color, resembles so strongly hypersthene as to be readily mistaken for it upon cursory examination. The inclusions referred to are determined to consist of characteristic heart-shaped and geniculate twins of rutile, and pointed pyramidal crystals of octahedrite. Others show a flat tabular development, somewhat similar to that of brookite, though these could not be positively determined as that mineral. Associated with the above were numbers of hexagonal, clove-brown plates appearing in cross section as sharp lines. A gradation between these plates and large masses of ilmenite was traced. It thus appears that these inclusions are all titaniferous minerals.

The second kind of hornblende is the compact, strongly pleochroic common green hornblende, and the third kind is a non-compact reedy variety of light green hornblende. This last is probably secondary, but secondary after the original hornblende, thus not affecting essentially the character of the rock.

The pyroxene is represented by a monoclinic variety and by the orthorhombic bronzite. The presence of olivine was determined with considerable doubt. None of the remaining minerals show anything of special interest.

The leading essential constituents described are combined in variable quantities, and accordingly a number of different mineralogical types of rocks are produced. The important types which will be described are hornblende-gabbro, consisting essentially of hornblende and labradorite; gabbro, consisting of monoclinic pyroxene and labradorite; and bronzite-norite, com-

[1] Petrographische Untersuchungen über die Noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. VAN HORN. Tsch. Mitt., V Heft, 17 Bd., 1897, p. 409.

posed of bronzite and labradorite. These various mineralogical types exhibit very interesting ranges in texture, to which attention will be called. The hornblende-gabbro of granitic texture is the prevailing rock. An analysis of such a rock shows the following composition:

ANALYSIS OF HORNBLENDE-GABBRO BY MR. GEORGE STEIGER.

SiO_2	49.80	Na_2O	2.22
TiO_2	.79	H_2O 100°−	.13
Al_2O_3	19.96	H_2O 100°+	1.71
Fe_2O_3	6.32	P_2O_5	.07
FeO	.49	CO_2	.15
CaO	11.33		
MgO	7.05		100.63
K_2O	.61		

In one of the hornblende gabbros a porphyritic texture is very pronounced. Porphyritic brown hornblendes, which are poikilitic from inclusions of feldspar and a few grains of augite, lie in an imperfectly ophitic groundmass. This rock grades into a finer grained nonporphyritic granitic textured gabbro. Both mineralogical and textural variations are well shown in another occurrence, in which the relations of the respective varieties are clearly seen. The normal granitic hornblende-gabbro is cut by numerous narrow bifurcating dikes, which are very dark, of fine grain, and stand out clearly from the main mass of the coarse-grained gabbro. These dikes contain a larger percentage of biotite than is found in the normal gabbro, but most interesting is the presence along the sides of the dikes of a well-marked parallel arrangement of the minerals. This is presumed to be a true flow structure consequent upon the flowage of the magma, where it was forced in the fissures, as none of the minerals bear indications of secondary origin, and show but faint evidence of the effects of pressure.

These dikes, as well as the main mass, are cut by a coarse-grained bronzite-norite. Bronzite, hornblende, and labradorite are the essential constituents of this rock, arranged in order of

their importance. The following analysis gives its chemical composition:

ANALYSIS OF BRONZITE-NORITE BY MR. GEORGE STEIGER.

SiO_2	48.17	Na_2O	1.34
TiO_2	1.00	H_2O 100°−	.19
Al_2O_3	25.26	H_2O 100°+	2.00
Fe_2O_3	1.13	P_2O_5	.07
FeO	6.10	CO_2	.43
CaO	9.53		
MgO	4.22		100.17
K_2O	.73	MnO, etc., not looked for.	

The last gabbro occurrence to be mentioned is one in which we find the normal type of hornblende-gabbro cut by a dike in which monoclinic pyroxene is in about equal quantity with the hornblende. This evidently represents a transition towards a true gabbro. This exposure of gabbro is cut by a peridotite, which is feldspathic and concerning which detailed statement will be made in the following pages.

The rocks just described may be compared in their variation to those described by G. H. Williams [1] from Maryland, by Chester [2] from Delaware, and by Fairbanks [3] from California. A series of basic rocks similar in many respects to those of Crystal Falls has also been described recently in two interesting papers by van Horn [4] and Schaefer.[5]

Peridotites.—The peridotites are all coarse-grained rocks of very dark color, consisting of the following chief mineral con-

[1] The gabbros and associated hornblende rocks occurring near Baltimore, by G. H. WILLIAMS, Bull. U. S. Geol. Surv., No. 28, 1886. Outline of the geology of Maryland, Baltimore, 1893, p. 39.

[2] The gabbros and associated rocks in Delaware, by F. D. CHESTER, Bull. U. S. Geol. Surv., No. 59, 1890.

[3] The geology of Point Sal, by H. W. FAIRBANKS, Bull. Dept. of Geol., Univ. of Cal., Vol. II, No. 1, 1896, p. 56 et seq.

[4] Petrographische Untersuchungen über die noritischen Gesteine der Umgegend von Ivrea in Oberitalien, by F. R. VAN HORN, Tsch. Mitt., Vol. 17, 1897, pp. 391–420.

[5] Der basische Gesteinszug von Ivrea im Gebiet des Mastallone-Thales, by R. W. SCHAEFER, Tsch. Mitt., Vol. 17, 1898, pp. 495–517.

stituents: pyroxene (monoclinic and orthorhombic), olivine, hornblende, and biotite. Associated with them are feldspar, apatite, green and brown spinel, and iron oxide. The relative proportions of these minerals differs much, and yield different well-known rocks. The types are not sharply separated, but are found, both in the field and under the microscope, to grade into one another. The purest form of peridotite is the wehrlite, composed essentially of olivine and augite. Where, besides these minerals, hornblende is present in large quantities, the rocks belong to the amphibole peridotite type and approach Williams' cortlandtite. In some specimens the biotite is almost in sufficient abundance to warrant the naming of the rock biotite-peridotite. Again, feldspar is present in comparative abundance and the rock is a feldspathic wehrlite, and approaches an olivine-gabbro or an olivine-hornblende-gabbro.

A number of exposures of the peridotites have been examined, but only one will be described here, and that has already been referred to under the gabbros. This peridotite cuts the gabbros. Sections made from different specimens taken from the exposure would be named, if considered separately, amphibole-peridotite, wehrlite, or even olivine-gabbro. This is the same exposure from which was taken a specimen described by Patton [1] as hornblende-picrite. In this rock there occur the following essential mineral constituents, given in order of crystallization: augite and olivine, apparently contemporaneous, orthorhombic pyroxene, hornblende, biotite and feldspar.

Of the mineral constituents forming the rock, augite is the only one which is automorphic, and then only when it is partially or wholly surrounded by feldspar. The olivine is in rounded individuals which are never associated with the augite in such a way as to enable their relative periods of crystallization to be determined. Orthorhombic pyroxene, apparently bronzite, occurs in grains inclosed in hornblende, and also forms

[1] Microscopical study of some Michigan rocks, by H. B. PATTON, in Sketch of the geology of the iron, gold, and copper districts of Michigan, by M. E. WADSWORTH, Rept. State Board Geol. Surv. for 1891, 1892, 1893, p. 186.

a narrow zone around the olivine. The hornblende is predominately a brown variety, showing strong pleochroism; **a** is light cream yellow, **c** is yellowish-brown, and **b** is reddish-brown. **b>c>a.** Patton [1] has already called attention to the exceptional pleochroism of this hornblende, in which the brownish color is that of rays vibrating parallel to the orthodiagonal axis. The brown hornblende is accompanied by a small quantity of green hornblende, which is in crystalline continuity with the brown, and is apparently original. The biotite began to crystallize before the hornblende had ceased growing, as we find it in ragged plates included by it, especially upon the periphery of the individuals. It is normally the least well-developed mineral present. Feldspar is present at times in small quantity, and forms the mesostasis. The olivine possesses a certain interest, as it is surrounded by zones[1] of different minerals; first, orthorhombic pyroxene, surrounded in its turn by green compact hornblende, which is in optical continuity with the predominant brown hornblende of the rock. This green hornblende lies next to the feldspar, and is traversed by anastomosing tabular feldspar growths.

From the relations described as existing between the various minerals composing the peridotite, it seems that the following stages may be outlined in the progress of the consolidation of this rock: From the coarse, even-grained character, and from the fact that neither a fine-grained groundmass nor glass is present, the conclusion is warranted that it consolidated very slowly, and must have, of course, at some time been under very high temperature. The olivine and augite were the first of the chief silicate constituents to form, and crystallized out of the magma at approximately the same time. The magma soon reached a condition unfavorable for further production of olivine, probably on account of increasing acidity. There was then formed the orthorhombic pyroxene occurring in a zone surrounding the olivine. The monoclinic pyroxene continued to grow during the formation of this orthorhombic variety, as it is

[1] Loc. cit., p. 186.

not surrounded by it. Finally, however, the condition of the magma was such that in the place of the monoclinic and orthorhombic pyroxene the crystallization of hornblende began.

I do not know what the conditions were which caused the formation of the hornblende subsequent to and in such intimate association with the pyroxene, surrounding it in zonal growth. An explanation of such occurrences has been attempted by Becke[1] in a recent article in which the conclusion is reached that the formation of hornblende and pyroxene depends upon changes in temperature and pressure. His explanation is based upon the facts of occurrence of pyroxene and hornblende in plutonic and effusive rocks, and also upon the well-known fact that at high temperature and atmospheric pressure hornblende cannot exist, but when fused recrystallizes as pyroxene, and upon the experiments of von Chrustschoff,[2] who has obtained hornblende at a temperature of 550° C., with the presence of water, under which conditions a high pressure must be developed. However, attention should be called to the fact that his explanation does not take into account other important factors which certainly influence the crystallization of minerals, for example, the chemical composition of the magma, and the fusion point and specific gravity of the minerals.

Whatever the factors are which determine its crystallization, the fact is that hornblende began to crystallize in the place of pyroxene. The biotite appears to have been formed at this time with the hornblende. The production of the hornblende and biotite continued until the remaining magma had reached the composition of basic feldspar, which then crystallized and now forms the mesostasis. A zone of orthorhombic pyroxene succeeded by one of hornblende has been described as surrounding the olivine in this peridotite. The term "reaction-rims" has been

[1] Gesteine der Columbretes; Anhang: Einiges über die Beziehung von Pyroxen und Amphibol in den Gesteinen. By F. BECKE: Tsch. Mitt., Vol. 16, 1896, pp. 327–336.

[2] Bull. de l'Academie des Sciences, St. Petersburg, 1890, 13. Cf. BECKE, loc. cit., p. 337.

applied to similar zones by various observers. It seems to me that this term is inapplicable to such zones. It is not probable that in such a case as this there is a reaction in a strict sense between the magma and the olivine. Moreover, the zones should not be compared to the "resorption-rims" found so commonly in certain effusive rocks, where, from the fusion of hornblende crystals, pyroxene has been produced. Such a zonal growth around the olivine seems to me comparable to the case described by Washington,[1] where colorless diopside phenocrysts are surrounded by a narrow border of yellowish-green augite, which corresponds to the small augites in the groundmass, or to those cases which are so common in plutonic rocks, even in this rock described, where hornblende is found surrounding the pyroxene.

A general explanation which would account for the successive crystallization of pyroxene and hornblende in this rock should be applicable to such a zonal growth as occurs around the olivine, taking into consideration, of course, the probability that a factor of slight importance in the one case may be the controlling factor in the other. Such occurrences seem clearly to indicate a change in the chemical composition of the magma as the chief factor, but influenced more or less strongly by the pressure, the temperature, and also by other factors.

An analysis of this peridotite is given below:

ANALYSIS OF PERIDOTITE BY DR. H. N. STOKES.

SiO_2	44.99	MgO	21.02
TiO_2	.97	K_2O	.74
Al_2O_3	5.91	Na_2O	.91
Cr_2O_3	.25	H_2O 110°−	.63
Fe_2O_3	3.42	H_2O 110°+	3.19
FeO	8.30	P_2O_5	.05
MnO	trace	CO_2	trace (?)
NiO	none		
CaO	8.79		99.17

[1] Italian Petrological Sketches, 4, The Rocca Monfina Region, by H. S. WASHINGTON, JOUR. GEOL., Vol. V, 1897, p. 254.

Chemical relations of the series.— In the preceding pages the mineralogical evidence has been given of the variations under discussion. In the following tables there are reproduced the analyses which have been given of the typical members of the different classes. They are arranged in order of diminishing acidity. In Table I the complete analyses are given.

I.

	1	2	3	4
SiO_2	58.51	49.80	48.17	44.99
TiO_2	.72	.79	1.00	.97
Al_2O_3	16.32	19.96	25.26	5.91
Cr_2O_3	none			.25
Fe_2O_3	2.11	6.32	1.13	3.42
FeO	4.43	.49	6.10	8.30
MnO	trace	——[1]	——[1]	trace
NiO	none	——	——	none
CaO	3.92	11.33	9.53	8.79
MgO	3.73	7.05	4.22	21.02
K_2O	4.08	.61	.73	.74
Na_2O	3.11	2.22	1.34	.91
H_2O at 110°	.23 100°—	.13 100°—	.19 110°—	.63
H_2O above 110°	2.00 100°+	1.71 100°+	2.00 110°+	3.19
P_2O_5	.30	.07	.07	.05
CO_2	none	.15	.43	trace?
	99.46	100.63	100.17	99.17

II.

PERCENTAGES OF CHIEF OXIDES REDUCED TO 100.

	1	2	3	4
SiO_2	60.36	49.80	49.41	47.33
TiO_2	.75	.79	1.02	1.02
Al_2O_3	16.83	19.96	25.96	6.22
Fe_2O_3	2.17	6.32	1.16	3.60
FeO	4.57	.49	6.25	8.73
CaO	4.04	11.33	9.77	9.25
MgO	3.85	7.05	4.32	22.11
K_2O	4.21	.61	.74	.78
Na_2O	3.21	2.22	1.37	.96

[1] MnO, etc., not looked for.

III.

ATOMIC PROPORTIONS OF METALS.

Si	55.85	46.53	45.90	42.48
Ti	.53	.56	.72	.70
Al	18.41	22.03	28.50	6.60
Fe	5.08	4.83	5.70	9.02
Ca	4.04	11.42	9.79	8.98
Mg	5.32	9.85	6.01	29.67
K	4.99	.74	.89	.91
Na	5.78	4.04	2.49	1.67

In Table II there is given the percentages of chief oxides reduced to 100, and in Table III the atomic proportions of the metals.[1] The analyses show that all of the rocks contain a moderately large amount of water. Nevertheless, they are sufficiently well preserved to warrant a discussion of their analyses for classificatory purposes. Indeed, No. 4 is remarkably fresh for so basic a rock. With reference to analysis No. 1, it may be stated that the rock is, on the whole, one which it is somewhat difficult to place definitely in the existing division of rock families. The large amount of lime and relatively low percentage of alkalies prevent placing the rock with the syenites, which possibly the presence of the large amount of orthoclase might lead one to do if the rock were studied with the microscope alone. On the whole, it approaches close to the monzonites, according to their chemical composition as given by Brögger.[2] From this it differs, in that the lime, 3.92 per cent., is too low to bring the rock within his limits, 4.52 to 10.12 per cent. However, if we consider the total of the alkaline earths, 7.55 per cent., in this rock, we find that it comes well within Brögger's range, 6.05 to 17.52 per cent., for a total of magnesia and lime. Moreover, the alkali total, 7.19 per cent., is too high to warrant its classification in the monzonite class as a representative of the type of the biotite-monzonite.

[1] These tables were calculated for me by MR. V. H. BASSETT, assistant in chemistry in the University of Wisconsin.

[2] Op. cit., Part II, p. 51.

On comparing the analysis with that of a normal diorite, we find the relative proportions of the alkalies are abnormal. Also the lime content is too low for rocks of this character; and, again, the magnesia is too high. From the above considerations it seems clear that the rock is related to the monzonites and diorites. However, it is so intimately associated with, and so evidently a facies of the tonalite, which is the dominant type where the mica-diorite occurs, that it is considered to be more closely related to the lime-soda-feldspar rocks in which the orthoclase is but accessory, than to the monzonite family of orthoclase-plagioclase rocks. It is, therefore, considered to be a mica-diorite. It has already been remarked that while for normal diorites the lime is too low, the magnesia is correspondingly too high. May we not with right consider this as indicating a relationship to the more basic rocks gabbros, in which magnesia forms a very important constituent and with which it is so intimately associated in the field? As against this interpretation, however, we have a very high percentage of alkalies and moderately high percentage of silica, which certainly warrant the exclusion of this rock from the gabbro family.

When we turn to a consideration of the gabbro-norites as represented by analyses Nos. 2 and 3, it is at once clear that if we accept, as has been done in the preceding pages, Brögger's[1] characterization of the diorite and gabbro families, that these rocks could not be included with the diorites as respectively normal diorite and bronzite-diorite, but must, from their abnormally low silica and alkali content and high alumina, lime, and magnesia content, be placed with the gabbros. Especially noteworthy in analysis No. 2 is the high percentage of alumina present. Normally, large alkali content accompanies high percentage of alumina. A reference to the alkalies shows this not to be true in this instance.

Analysis No. 4 is not to be taken as representing the most basic variety of peridotite in this district. From this alone the statement that the variations extend to the ultrabasic rocks

[1] Op. cit., Part II, pp. 35, 39.

would hardly be warranted. As has already been said, however, the rock of which the analysis was made is one which is feldspathic, and represents a transition upward into the gabbro.

Examining the series of analyses together, we see that in passing from the most acid to the basic end the alumina increases very rapidly to 25.96 per cent., until it reaches the extreme basic rock, when it drops suddenly to 6.22 per cent. The analyses also show an increase in the same direction in iron, as is best brought out in Table III. The alkalies increase with diminishing silica, whereas the magnesia, which for rocks of this character is very characteristic, shows a decided increase. In the gabbro-norite-peridotite portion of the series, analyses Nos. 2, 3, and 4, the lime shows a constant diminution, corresponding to the increasing magnesian character of the rocks. Likewise the potash increases as the soda diminishes. The rocks represented by the analyses are believed to belong to a series ranging from a diorite on the one hand through hornblende-gabbro and norite to a peridotite on the other. It is evident that a gap exists between the gabbro and diorite. The diorite represents a gradation towards the orthoclase rocks of essentially the same acidity. On this acid side of the series the microscope also shows variations to a tonalitic and even granitic rocks very rich in quartz and orthoclase, probably very much more acid in character than the diorite represented in the analyses.

Relations of the rocks of the series.—The rapid changes in mineralogical composition and texture in a single rock exposure, and the changes thus occasioned from one type into another through intermediate facies, show very clearly the intimate relationship of the Crystal Falls rocks to one another, and warrants the assumption that they all belong to a geological unit, a conclusion long since reached by Williams[1] for a similar group of rocks, "The Cortlandt Series" from New York. Variations very similar

[1] The peridotites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS, Am. Jour. Sci., Vol. XXXI, 1886, pp. 26–41.

The norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS. Am. Jour. Sci., Vol. XXXIII, 1887, pp. 135–144, 191–199.

to those here described have been well described by Messrs. Dakyns and Teall from some Scottish plutonic rocks.[1] The field studies have shown the relations of the various members of this series from Crystal Falls to be as follows: The diorite is found cutting the hornblende-gabbro. The gabbro is also found to be cut by a dike of biotite-granite. The relation of this particular dike to the diorite could not be determined; therefore it has not been described. In one case, however, a dike cutting a gabbro showed biotite-granite as a facies of the diorite. It is probable that the other dikes of biotite-granite occurring in the area are facies of the same widely distributed diorite magma. The hornblende-gabbro is cut by the bronzite-norite and the peridotite. It is thus evident that the eruption of the hornblende-gabbro was followed by that of a peridotite on the one hand and by a diorite, possibly even a granite, on the other.

It is a difficult matter to estimate quantitatively the amount of the one or the other rock type present in the Crystal Falls district. We are thus prevented from drawing from the predominance of the one kind or the other the conclusion that those represented in the minority are the results of the differentiation of a magma most nearly resembling in its original constitution that which predominates. Moreover, since the analyzed rock types were not selected as representatives of the extremes of the process of differentiation, it would not be wise to endeavor to give the mean composition of the parent magma, from the analyses of the differentiation products which have been presented. The main thesis, however, seems to be established that the separation of a magma into the various products described has taken place, as is indicated by the relations in the field, and as has been shown by the microscopical and chemical analyses.

From the relations described as existing between the various

The gabbros and norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y., by G. H. WILLIAMS, Am. Jour. Sci., Vol. XXXV, 1888, pp. 438–448.

[1] On the plutonic rocks of Garabal Hill and Meall Breac, by J. R. DAKYNS, ESQ., M.A., and J. J. H. TEALL, ESQ., M.A., F.R.S., F.G.S., Q. J. G. S., Vol. XLVIII, 1892, pp. 104–121.

kinds of rocks, it was seen that the hornblende-gabbro was unquestionably the one which first reached its present position. Whether this is to be regarded as itself representing the composition of the parent magma, or only as a differentiation product of a still deeper seated igneous mass, cannot of course be determined. Be that as it may, the fact, which has been proven, remains, that given the period of eruption of this hornblende-gabbro as a starting point, and possibly this magma as the original one, the forces of differentiation have been active in two directions, towards increasing acidity and increasing basicity, in agreement with the law of succession of igneous rocks as propounded by Iddings.[1]

J. MORGAN CLEMENTS.

[1] The Origin of Igneous Rocks, by J. P. IDDINGS, Bull. Phil. Soc. Wash., Vol. XII, 1892, p. 145.

STUDIES FOR STUDENTS.

THE DEVELOPMENT AND GEOLOGICAL RELATIONS OF THE VERTEBRATES.

The object of these studies is in no wise to attempt to furnish a course in vertebrate palæontology, but rather to place before the student of geology, who has no time for the study of the morphological and phylogenetic questions involved, a brief statement of the results achieved by the workers in the more narrow field. The value of vertebrate remains as indicators of the time changes in the past is so well recognized that it is hoped that an orderly summary of the fossil vertebrates, with a brief indication of the lines along which they have developed, and references to the most helpful literature, may be of value to the student, both within the limits of these articles and in aiding him to extend the work by collateral reading.

PART I. THE FISHES.

FISHES are, in the popular language of Bashford Dean, "back-boned animals, gill-breathing, cold-blooded, and provided with fins." This definition may well be used if we remember that the "back-bone" is not always bony, that it may be entirely cartilaginous or only partly ossified. A similar condition may be found in all the other bones of the body and is the chief reason that the early history of the fishes is hidden in the deepest obscurity, for it is one of the most commonly recognized facts of palæontology, as well as one of the most deplorable, that only under the most favorable conditions can the soft structures of any body be preserved. From this it is easily understood why the earliest remains of fishes that we possess are those of forms in which the skeleton has progressed so far as to be formed of solid cartilage at least, and generally of cartilage with local ossification or calcification.

The following classification of the larger groups of the fishes is in general use :

Class : PISCES.
- Sub-Class : *Marsupiobranchii.*
- *Ostracodermi.*
- *Elasmobranchii.*
  - Order : *Selachii.*
  - *Batoidi.*
- Sub-Class : *Holocephali.*
- *Dipnoi.*
  - *Sirenoidei.*
  - *Arthrodira.*
- Sub-Class : *Teleostomi.*
  - Order : *Crossopterygii.*
  - *Actinopterygii.*
    - Sub-Order : *Chondrostei.*
    - *Teleocephali.*

The first of these, the *Marsupiobranchii*, are not well understood in their relations to the true fishes. The most common of the group are the hagfishes and the lampreys of the present time. They differ from all other vertebrates by the entire absence of the lower jaw and of the pelvic and pectoral girdles of bone that support the hind and the fore limbs. Whether these conditions are the primitive stages of a developing fish or are the final stages of a degenerate structure, is still an unsettled question, and it is at this point of difficulty that we turn to the palæontological record. However, we can gain but little from the palæontology of the forms. A single specimen from the Old Red Sandstone of Scotland is the representative of the fossil *Marsupiobranchii*, and it is even doubtful whether this specimen is correctly referred to that group. The specimen shows the presence of well defined rings in the position of the vertebræ, a stage in advance of the recent forms, which would indicate for them a degenerate structure.

The earliest remains of fishes known are from the Lower Ordivician rocks of the Grand Canyon region of the United States. These are the very imperfectly preserved remains of what seem to be scales and bones of fishes whose affinities cannot be made out from the material.

Before attempting to take up the different forms of the true fishes it may be well to consider briefly those points in the anatomy of fishes in general where changes have taken place resulting in the modern type of the bony fishes. There are three regions in the skeleton that have been used more than any others in making out the different groups of the fishes and their phylogenetic development: 1. The gradual ossification of all the bones of the body. 2. The development of the vertebræ. 3. The development of the fin of the modern type.

The first of these is the gradual process of strengthening the skeleton by the addition of solid matter which has been at work ever since the origin of the class and is still incomplete in many forms. It is only in the last sub-order of the *Teleostomi*, the *Teleocephali*, that the process is at all complete. Before the actual formation of bone in the supporting tissues of the body the cartilage was frequently strengthened by the deposition of calcareous particles. This is the condition found in the remains of most of the early sharks.

The second process, the development of the vertebræ, is of considerable importance not only in the development of the fishes, but as we shall see, in the earliest of the *Amphibia* as well. The most primitive condition of the spinal column is such as is well illustrated in the *Amphioxus*, one of the simplest of all the vertebrate phylum, the column in this case consisting of a continuous rod of cartilage, the notochord, extending through the body from the anterior to the posterior end and lying near to the dorsal side of the body. It is protected by several layers or sheaths of membrane in which the future vertebræ are developed. The development of the bony covering of this rod is foreshadowed by the appearance of the cartilaginous rings that have the same serial arrangement as the vertebræ of the more advanced types. A very important thing about the development of the vertebræ is the development on the superior and the inferior faces of the chordal sheath of bony arches that appear before the body proper, or centrum, of the vertebræ. The superior of these, the neural arch, protects the spinal cord

throughout the length of the vertebral column. The second is developed to the fullest extent only in the caudal portion of the column and there furnishes a protection for blood vessels. These arches may or may not be attached to the centrum in the adult form, but the bases are the first points of ossification and the rest of the vertebræ develops between them. The process is not complete in all of the fishes, and the gradual completion of the vertebræ is of great aid in determining the position of some of the fossil forms (Fig. 1).

Fig. 1. Schematic view of a vertebra. *n*, neural arch; *c*, centrum; *h* hæmal arch; *w*, notochordal canal.

The third, and perhaps the most important of the three regions of development is the formation of the fins, both paired and median. Whatever may have been the original form of the fish the first thing in the evolution demanded by their peculiar environment must have been the development of some form of keel that would not only aid the fish in its progress through the water, but would enable it to maintain any desired position both as to the relative depth below the surface of the water and as to lateral displacement. The first step in the accomplishment of this end was the development of long fins extending from the head to the tail. One pair of these was developed on the median dorsal and ventral lines, and persists in the dorsal, caudal, and ventral fins of the existing fishes. The second pair extended along each side of the body in a plane at right angles to the first and divided the body into approximately equal parts above and below. The paired fins, the pectoral and the ventral, are supposed to be remnants of these lateral folds or fins.

The development of the fins seems to have followed a very definite line that has served as a great aid in making out the classification of the various fossil and recent forms. Undoubtedly the first stage of the development of the fins was the formation of the long folds of the skin that were without any internal support, and capable of very complex, wavelike motion, and without any great power of resistance to impressed forces. Of this stage we do not have any trace in the preserved fossil forms for the reason already assigned, that soft parts are not preserved except under the most exceptional circumstances. We should expect it to occur in the remains of the *Marsupiobranchii*, if at all, but the single specimen preserved, *Paleospondylus*, does not show any evidence of such a fold. The function of the fin fold, to preserve the equilibrium of the fish, would demand some degree of resistance in the fold, and the next stage of the fin must have been the appearance of fine, hair-like rays of horny material, confined to the dermal part of the fold and not joined to the body proper. These were many in number, and only served to stiffen the fin without strengthening its attachment to the body. These fine rays have been called the actinotrichia. The second stage in the development of the fins was the fusion of certain of these actinotrichia at points of the greatest strain in the fins into larger and more solid elements that afforded a much greater power of resistance at those points. The comparatively large and strong cartilaginous rods thus formed have received the name of radials. The same necessity of resisting outside forces that caused the union of the actinotrichia to form the radials demanded a stronger attachment of the radials to the body wall of the fish, and this was accomplished by the separation of the proximal portion of the radial as a separate element, which became elongate and penetrated into the body wall, affording a very strong support to the radials. This proximal section is called the basal (Fig. 2).

Up to this point in the development of the fins the history of the paired and the unpaired fins is regarded as practically the same, for the paired fins were as yet but undifferentiated parts

of the lateral body folds. The reason for the development of one portion of the lateral fins over another is not well understood, but it has been suggested that at points of especial strain in the fold, points where, from the mechanical advantage of their

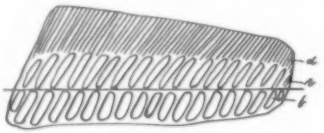

FIG. 2. Schematic unpaired fin; *b*, basal, *r*, radial; *d*, dermal margin of fin (after Smith-Woodward).

position, certain parts of the fold were able to assist in the propulsion of the body through the water, that the fins were especially well developed, and that there appeared lappetlike prominences in the position of the present paired fins. As these lappets assumed more and more of the function of swimming organs, and less of balancers, they required an even stronger support than before, and this was accomplished by the fusion of the basals together and also of the radials, though to a less extent. As the lappets of the lateral fin grew in importance, the intermediate portion dwindled away until all trace of the original fold is lost between and beyond the paired fins. The final step in the development of the fins was the appearance beyond the distal ends of the radials of fine dermal elements that have much the appearance of the original actinotrichia. These serve the purpose of supporting the web at the extremity of the fins.

Another line of development of the fishes is closely allied to the development of the fins. The median fin that originally extended from the head of the animal to the tail has in the course of its development gradually retreated toward the posterior portion of the body until it is represented by a single caudal fin and one or more separated elements called from their positions the dorsal and the anal fins. The caudal fin has assumed different positions in relation to the terminal portion of the

spinal column. In the original condition the dorsal and the ventral parts of the fin were equally developed, and the vertebral axis divided the fin into two equal parts, so that the fin presented a rounded or slightly acuminate appearance. This is called the diphycercal condition. Another, and a very common condition among the more primitive forms of fish, is where the ventral portion of the caudal fin is developed at the expense of the dorsal, and the terminal portion of the vertebral axis is bent upward at the end. This is called the heterocercal condition. The form most commonly found in the modern forms of fishes is that in which both the dorsal and the ventral portions of the caudal fin are developed more than the main portion of the fin, but about equally themselves. This is called the homocercal condition, and was for a long time considered as the primitive condition, or at least more primitive than the heterocercal. It is shown to be untrue by the fact that even in the highest types of the bony fishes the extremity of the notochord is bent upward as in the heterocercal form of the tail. The progress of development of the tail seems to have been from the diphycercal through the heterocercal to the homocercal.[1]

The oldest remains of fishes that are definitely known come from the Upper Silurian and the succeeding rocks as high as the Carboniferous. The group called *Ostracodermi* has long been denied a position among the fishes by certain authors, the principal objection being the seeming lack of any lower jaw, which is regarded as one of the principal characters of the vertebrates. Because of this feature and the appearance of some of the forms which is similar in a general way to that of the Trilobites, the group has been considered as belonging to the *Crustacea*, but there are so many other characters that unite them with the

[1] A discussion of the facts here pointed out, with much more that is valuable to the student, will be found in a recent book by Bashford Dean, *Fishes, Living and Fossil*, an outline of their forms and probable relationships, Columbia University Biological Series, Macmillan & Co., 1895. This book takes up the various forms of fishes in a popular way that will not be beyond the student of geology who has the principles of biology. The large number of excellent illustrations will be found to be of great value in getting an idea of the fossil forms.

fishes that no less an authority than Smith-Woodward has placed them among the fishes. In general, the group is distinguished by the fact that the bones are not ossified; that the paired fins and the lower jaw are absent, and that the anterior part of the body is covered by large, bony plates that are developed in the skin and have no connection with the cartilaginous skeleton. The group is divided into three families: *Pteraspidæ*, *Cephalaspidæ*, and *Pterichthidæ*.

Pteraspidæ.—This family is confined almost exclusively to the Devonian, the Old Red Sandstone of England and Scotland. It contains the simplest and most archaic forms of the *Ostracodermi*. The anterior part of the body was covered by two large plates, a superior and an inferior, that served as a complete armor for that part of the body. The eyes protruded from openings formed by notches in the adjacent edges of the two plates. The upper plate is sometimes marked by grooves that are supposed to indicate the course and distribution of sensory tracts such as are found in the skulls of the shark and many of the more advanced types of fishes. The posterior part of the body was covered by many small rhomboid scales. It is probable that the forms were bottom feeders, and that the common food was the abundant molluscan fauna of the Devonian seas. *Pteraspis* and *Holaspis*, from the Devonian of England, and *Palæaspis*, from the Upper Silurian of Pennsylvania in the United States, are the best known of the family.

Cephalaspidæ.—In many respects the members of this family resemble the last, the anterior part of the body is covered by well developed plates, while the posterior portion is protected by rhomboid scales. The size was, in general, smaller than either of the other families, seldom reaching more than a foot in length. The head was large and curiously like that of a Trilobite in external appearance. The anterior edge was rounded, and there were two lateral posterior extensions in a position analagous to that of the genal spines in the Trilobites. The eyes were located near the center of this plate. The scales that formed the protection of the posterior part of the body are

large and arranged in rows, the mid-dorsal row developing an acuminate ridge that has the appearance of a dorsal fin. The tail was distinctly heterocercal. In some of the more perfectly preserved specimens there seems to be an indication of the presence of external gills at the base of the posterior lateral spines of the head plate. All the known forms are from the Upper Silurian and the Devonian rocks of England and Europe. Among the best known of the genera are, *Cephalaspis*, *Auchenaspis* and *Trematáspis*

Pterichthidæ.—This family presents many important steps in advance of the other two, the anterior part of the body is not protected by single plates, but by an armor made up of the union of several small plates both upon the upper and the lower sides. The posterior portion was, as in the other forms, covered with small scales. Perhaps the most peculiar thing about the family is the presence upon the sides of the body, near the anterior end, of elongate, movable appendages that perhaps served as swimming organs, although in one of the later and more specialized of the forms the appendages become anchylosed to the adjoining plate, and lose all power of motion. These appendages are regarded as the homologues of the posterior extensions of the head plate of the *Cephalaspidæ*. The *Pterichthidæ* are most commonly known from the Devonian of the Old World. *Pterichthys*, *Asterolepis*, and *Bothriolepis* are well-known European forms. From the New World *Bothriolepis* has been described from the Devonian of Canada, and from the same horizon in Ohio incomplete remains have been described by Newberry as *Acanthaspis* and *Acantholepis*. It is necessary here to warn the student against a confusion that may arise between the old classification present in so many of the text-books and the one here used. The *Pteraspidæ*, *Cephalaspidæ*, and the *Placodermi* were regarded as orders of the highly artificial group, *Ganoidei*. The last order included not only the *Pterichthidæ*, but more highly developed forms that are now known to belong to the *Dipnöi*.

The *Elasmobranchii* are the most primitive forms that hold an

undisputed position among the fishes. Including both the sharks and rays, the group may be defined as made up of forms in which the skeleton is cartilaginous, the skin filled with fine calcareous particles (shagreen), the tail heterocercal, and the external openings of the gills mere slits in the skin of the neck unprotected by an operculum. In the previous sub-class there are no remains preserved of distinct vertebræ, but in the sharks the beginning of the vertebræ is seen in the formation of cartilaginous rings in the sheath of the notochord. These rings are of varying degrees of development in the different forms, in some forming mere circular bands around the chord, while in others they are nearly closed by the ingrowth of the cartilage that tends to segment the chord off into intervertebral elements. There is always attached to the superior and the inferior faces of the cartilaginous ring the neural and the hæmal arches that carry the spinal cord and the blood vessels.

The most primitive of the fossil sharks comes from the Lower Carboniferous of Ohio. This form, *Cladoselache*, is, in many respects, quite close to the hypothetical type form of all the fishes, the body is long and slender, and there were seven gill slits in the neck, which seems to be the number characteristic of the earliest forms. The unpaired fins have not progressed beyond the second stage of development, as outlined in the first part of this paper, that is, the fin fold is supported by small rods of cartilage, radials, that are not attached to the body wall. The paired fins are in a scarcely more developed condition, the lateral fold has disappeared, but the two lappets that represent the pectoral and the ventral fins have not progressed beyond the stage of the radial support, and are consequently of no value to the fish as swimming organs, but must have served merely as balancers. The tail was abruptly heterocercal. The whole form was rather small, not reaching a length of more than six feet at the outside.

Acanthodes, a rather small form from the Coal Measures of England, seems to present a step in advance of *Cladoselache*. The shagreen particles that are scattered throughout the skin

of most of the sharks are in this form enlarged into scalelike forms that fit tightly one against the other and afford a complete cover for the body. The paired fins are more strongly developed than in the previous form, and are better fitted for the purpose of balancing the body as well as assuming, to some slight extent, the function of locomotion.

Climatius, from Devonian Old Red Sandstone of Scotland, is of considerable interest from the fact that between the paired fins on the two sides there are developed many smaller fins, located along the line of the primitive fin fold. These are regarded as the remnants of the disappearing lateral body fold. The form represents a stage in this respect ancestral to both *Cladoselache* and *Acanthodes*, but is in other respects in advance of both of them.

Pleuracanthus, from the Permian, is one of the most interesting of the fossil sharks. It represents a stage considerably in advance of the forms already described. The radials of the median fins have separated off the proximal basal segments that afford the strong attachment of the fin to the body wall, and there is developed to some extent the dermal elements of the external edge of the fin that are found in the fins of the modern bony fishes. The paired fins present a very interesting condition, the fore limb having the character of a dipnoan fin, and the hind limb the characters of the more advanced type of the fish fin. To understand this condition it is necessary to go back to the formation of the paired fins from the lateral fin folds. The gradual development of the functional swimming fin was by the concresence of the basal and the radials to form strong, though somewhat flexible supports for the membrane of the fin. This was accomplished in two ways. In one the basals united and formed a long median axis upon each side of which the radials were attached after the manner in which the barbs of a feather are attached on each side of the quill. This type was originally supposed to be the most primitive form of the fin, and so it was given the name of *archipterygium*. In the other type the basals fused into one or more pieces that were

confined to one side of the fin, and the radials formed the other side ; this is the type of fin present in the more advanced fishes; it is called the *ichthyopterygium*. See Fig. 3.

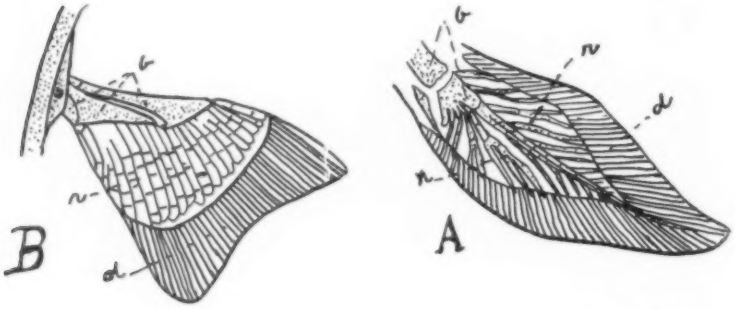

FIG. 3. *A*, archipterygium ; *B*, ichthyopterygium ; *b*, basals ; *r*, radials ; *d*, dermal margin.

Besides the peculiar condition of the fins, *Pleuracanthus* presents other remarkable features. Notable among these are the presence of a large spine that projected from the posterior edge of the skull, and the fusion of the shagreen denticles on the superior surface of the head into numerous dermal plates. In *Pleuracanthus*, as well as the forms previously mentioned, the center of the vertebræ had not yet become very well developed, and all that is found in the preserved specimens is the line of neural arches above the position of the notochord and the hæmal arches below.

Chondrenchelys from the Carboniferous of Europe was in many respects similar to *Pleuracanthus*, but there is one point of decided advance, the vertebræ were well formed, though still cartilaginous, and the inner part of the cartilaginous vertebral ring was well filled so that the chord was divided into segments by constrictions at the center of the vertebræ.

With the appearance of the sharks of the type of *Chondrenchelys*, the modern form is outlined, and since the Carboniferous there has been no great change in the general structure

of the group. One thing is important, however, and that is the changes that took place in the teeth of the many forms that were developed during the Carboniferous time. There seems to have been developed two types of teeth that indicate a very different mode of life. In one of these groups the teeth became flattened and adapted to crushing or grinding the shells of molluscs and crustaceans that formed the food supply. The surfaces of the teeth were sculptured in the most intricate manner, affording an enlarged and more efficient triturating surface. The different patterns of this sculpture seem almost endless. To these forms have been given the name of the "pavement-toothed sharks." *Janassa*, *Petalodus* and *Cochliodius*, all from the Carboniferous rocks are perhaps the best representatives of the group. *Cestracion*, the modern Port Jackson shark, is the single living representative. In the second group the teeth were developed in accordance with the demands of a more active and rapacious habit. They are more or less triangular in outline, and the edges are frequently finely serrated, affording a very firm hold as well as forming most efficient cutting organs. This type reached its development later than the pavement-toothed forms. The largest form, *Carcharias*, in which the teeth reached a length of six inches, is known from the Eocene of both the Old and the New Worlds. Other typical forms are *Sphenodus*, *Lamna*, and *Carcharodon* from the Mesozoic of Europe and many forms that are regarded as subgenera of *Carcharias* in North America.

One type of fossil that must be mentioned is the *Ichthyodorulite*. These are detached spines that are found in great abundance in the Carboniferous and Mesozoic rocks, and from which a large number of genera have been named. In the modern sharks the anterior end of the fins, and especially the dorsal fin, is frequently strengthened by the development of a strong spine that serves as a cutwater. These spines were much more strongly developed in the more primitive sharks, and were subject to the greatest degree of modification in form, structure, and ornamentation. As they were so strong they would naturally

be preserved through the accidents of fossilization more often than the softer structures of the skeleton.

The Rays or *Batoid* branch of the *Elasmobranchii* are of doubtful origin, other than the fact that they differ from the true sharks only in the modifications that are attendant on the extreme flattening of the body due to the habit of bottom feeding. They probably originated as far back as the Carboniferous time, although well-preserved forms are not known from rocks earlier than the Jurrassic. *Rhinobatis*, an existing genus, is known from the Oolite.

The part played by the sharks in the waters of the Palæozoic oceans seems to be very much the same as that played by the recent bony fishes in the modern waters. The variety of forms was seemingly endless, and the adaptations to various conditions of life, and to different means of obtaining food, bear witness, not only to the large number of forms, but to the strength and dominance of the type.

. The *Holocephali*, the Chimeroids, is a peculiar, aberrant group, that is allied on the one hand to the sharks and on the other to the Dipnoans. The structure of the fins and the vertebral column is the same as in the sharks, but the structure of the head and the arrangement of the teeth is almost the same as the dipnoans. There is a single broad dental plate in the lower jaw, and two plates in the upper jaw instead of numerous isolated teeth. The surface of these tooth plates is variously modified by the addition of knobs, ridges, and other irregularities, to increase the grinding surface. Little is left of the fossil forms but the teeth and the spines that stood at the anterior end of the dorsal fin as in the sharks. Fossil forms are *Ischyodus*, *Myriacanthus*, and *Squaloraja*, all from the Mesozoic.

The *Dipnoi* are, perhaps, the most peculiar of all of the fishes. For a long time considered as the linking type between the fishes and the amphibians, they are now generally regarded as a degenerate group that originated from the stem of the Crossopterygian *Teleostomes*. They are characterized by the absence of a connecting bone, the quadrate, between the skull proper

and the lower jaw. This condition, called autostylic, is found in the preceding group. Other characters are the modification of the swim bladder, in the living forms at least, as a breathing organ that assumes to some extent the structure of the lungs of the land vertebrates, the presence of tooth plates instead of teeth in the jaws, the archipterygial structure of the fins and the diphycercal tail. At the present time there are only three genera of the group living, but their wide distribution points to a very great development in earlier times. The existing genera are *Protopterus* from Egypt, *Ceratodus* from Australia, and *Lepidosiren* from South America. In these forms, as in the fossils, the vertebræ are incompletely ossified, the centrum remaining cartilaginous, while the upper and the lower arches are fairly well ossified. The major portion of the skeleton is well ossified, thus showing a condition in advance of the sharks and Chimeroids.

The *Dipnoi* are an exceedingly ancient group; even as early as the Devonian they had developed most of the characters that distinguish them from the other fishes. While it is altogether probable that they originated from the primitive shark stem, the point of origin seems to be totally lost, for the well-developed Dipnoans are found contemporaneous with the earliest of the sharks. Of the early *Dipnoi*, perhaps the most interesting is *Dipterus* from the Old Red Sandstone. This form had well-developed cycloidal scales, the type of the modern fish scale, while the sharks still had the shagreen denticles, and the Ostracoderms the thick, bony, rhomboid scales so characteristic of the early fishes. It had the skull protected by a roofing of dermal plates, and the teeth modified into large plates, with rough triturating surfaces. The plates were arranged as in the *Holocephali*, two in the upper jaw and one in the lower jaw of each side.

Phaneropleuron, from the same horizons in Scotland, is more primitive in some of the characters; for instance, the jaws are provided with many small, conical teeth, and the dorsal fin is continuous instead of being broken up into two or three seg-

ments. Specimens of this genus are known from the Devonian rocks of the province of Quebec in Canada. *Ctenodus*, from the Carboniferous of England, *Holodus* and *Palædaphus* from Devonian of Europe, *Mylostoma* from the Devonian of New York, and *Gnathorhiza* and *Strigilina* from the Permian of Texas, are all characteristic forms that have been described from the teeth.

A division of the *Dipnoi*, the *Arthrodira* are of especial interest, as they were at one time regarded as belonging with the *Pterichthidæ* in an order the *Placodermi*. The discovery of well-developed lower jaws and paired fins demonstrated that they could not belong among the primitive *Ostracodermi*, and the discovery of the manner of the articulation of the lower jaw to the skull showed that they belonged among the *Dipnoi*. They are among the most ancient of the fishes, ranging from the Upper Silurian to the Carboniferous. In the United States a large majority of the known remains have been taken from the Waverly Shales of Ohio. In Europe they are found in the Devonian Old Red Sandstone of England and Scotland. They were powerful, armored, predatory forms, in many cases of large size, that must have been a match for the largest sharks of the time. The armor in some of the genera was between two and three inches in thickness. The armor seems to have been confined in most of the forms to the anterior portion of the body, which has led to the belief that perhaps they buried the posterior part of the body in the mud and lay in wait for their prey rather than seeking it out and depending on their rapidity of movement and powerful jaws to obtain the mastery.

Coccosteus, a rather small form from the Devonian of England, is one of the best known of the group. It did not reach a length of more than one or two feet. The anterior part of the body is covered with an armor made up of several plates that extend back to about the middle of the body. The centra of the vertebræ are not preserved but the upper and lower arches outline the notochordal column. The dorsal fin is in the stage of the basals and radials and the posterior pair of fins is united to a distinct pelvic girdle. The armor of the

anterior portion of the body was very hard and polished in appearance, looking like the enamel scales of the "Ganoid" fishes and covered with small tubercles that were divided by the course of rather deep sensory canals. The armor plates were purely dermal in character having nothing to do with the true skeleton which was still made up of cartilage. One very peculiar thing was the presence of a very strong joint between the plates covering the head and those covering the shoulders. This joint must have permitted a great degree of motion in the vertical direction between the head and the body, though the purpose of such a motion is not understood. The posterior part of the body was covered by a thick integument entirely devoid of scales such as are present in the *Ostracodermi*.

The American forms of the *Arthrodira* were in general much larger and better developed than the European ones. They reached a total length of as much as ten or twelve feet and the sculpture of the armor and the variety of forms presented in the development of the jaws bear witness to the great variety of genera developed. The arrangement of the teeth is somewhat as in the Dipnoans, that is there were no separate teeth bordering the jaws but there were dental plates that were attached to the edges of the jaw; one peculiar thing about the plates is that they were not fixed as in the Dipnoans but were to a greater or less extent movable. In general the body form was like that of *Coccosteus* but the modifications of the tooth plate presents a very remarkable series. In *Dinicthys* they are developed as sharp cutting edges with a strong notch near the anterior end, in *Titanicthys* as a simple cutting edge, in *Trachosteus* and *Diplognathus* the edges of the plates were serrated and presented the appearance of being set with isolated teeth as in the ordinary arrangement of the fish jaw.

The last of the subclasses of the fishes is the *Teleostomes*. This group includes the old orders *Ganoids* and *Teleosts* that have been used for so long and are still commonly met with in the text-books of geology. The main distinction between them as seen by the geologist is the presence in the Ganoids of bony,

rhombic scales and in the Teleosts of horny, cycloidal scales. It is readily shown that these characters are of the most superficial nature and the condition of one group is easily found in the other, still as a general thing it may be said that a majority of the older forms had the rhomboid type of scale and the modern forms have the horny type. Bashford Dean discusses the relationships and descent of the Teleostomes in the following words, p. 145: "Johannes Müller, when separating Ganoids from Teleosts, recognized clearly even at that early date (1844) that the majority of the structural differences of these forms were bridged over in exceptional instances; there were thus Teleosts with bony body plates, as well as, it was afterwards found, a Ganoid, (*Amia*) with herringlike cycloidal scales. But he believed that three structural characters of the Ganoids separated them constantly from all Teleosts, and warranted the integrity of the groups."

These distinguishing characters were:—

I. A contractile arterial cone, containing rows of valves.

II. An intestinal spiral valve.

III. The interfusion (chiasma) of the optic nerves.

It was not until these differences were shown to be of little morphological importance that the two groups were merged in that of the *Teleostomi* (Owen, 1866). Thus transitional characters of the arterial cone of *Butrinus* were discovered by Boas. The Teleost, *Cheirocentrus* was found to present Ganoidean intestinal characters, and the optic chiasma, as Wiedersheim demonstrated, could no longer be regarded as of taxonomic or morphological value.

The descent of the Teleostomes, like that of the other groups, has long been a matter of speculation. Their affinities with the Dipnoans are generally admitted (Gunther, Gegenbaur, Haeckel, Smith-Woodward). Rabl derives them directly from a Selachian stem, regarding the Dipnoans as later evolved Ganoidean forms. Beard, on the other hand, even goes so far as to entirely separate the Teleostome stem from that of the shark, lungfish, an amphibian, deriving it with a close kinship

to the *Petromyzonts* (*Marsupiobranchii*), from the earliest vertebrates. Palæontology, however, has lately been giving rich contributions to this disputed problem, and there can at present be little doubt that the conditions in fossil fishes have demonstrated that in most ancient times Dipnoan and Teleostome were closely approximated. Although even in the earliest fossils they may be distinguished (*e. g.*, by the arrangement of the head-roofing derm bones), yet, as Smith-Woodward has noted, forms occur too clearly transitional to indicate anything less than genetic kinship. The Crossopterygian, whose ancient structure is well known, may well have been derived from an ancestor common to the Ctenodont (Dipnoan) and the Holoptychian; so that the gradual nearing of the Teleostome stem to that more fixed, of the Dipnoan, is a strong suggestion of its derivation. The later descent of the Ganoids from an ancestor closely akin to, if not identical with the Crossopterygian, is usually conceded. Teleosts, first occurring in the Cretaceous, are by evidence of fossils the almost undoubted survivors of an extensive group of transitional Mesozoic Ganoids. But whether all Teleosts are to be deduced from a single ganoidean phylum can at present hardly be established. Thus catfishes, or Siluroids, appear in many structural regards closely akin to the sturgeon; but as their fossil remains are lacking before the Eocene—when however, they appear to have been in every way as highly evolved as in recent forms—little clew has been given to their descent.

Teleostomes may, in the present connection, be briefly characterized in their two principal subdivisions.

I. *Crossopterygian*, the more archaic group, uniting the characters of shark, lungfish, and ganoid, retaining the ancient cartilaginous fin bases, radials, and basals in their lobate fins; in some forms (*Holoptyhchius*), the concrescence of the basal parts of the unpaired fins passing through the same evolution as those of the paired fins. Represented in the surviving *Polypterus* ("*Bichir*" of the White Nile) and in the slender *Polypteroid Calamoicthys* (of Calabar), and in the extinct *Holoptychius*, *Undina*, *Diplurus* and *Coelancathus*.

II. *Actinopterygian*, the spine-finned Teleostomes. Fins supported by dermal rays; ancient fin support greatly reduced, implanted in the body wall. Includes *Chondrosteans* (Ganoids) and *Teleocephali* (Teleosts).

Among the fossil forms of the Crossopterygians *Gyroptychius* and *Osteolepis* from the Old Red Sandstone of Scotland are very similar to the early Dipnoans in the general appearance of the body. The tail is somewhat heterocercal and the dorsal fin is divided up into segments; but the teeth are numerous and arranged along the edges of the jaws instead of being reprerented by single plates. The entire body was covered by solid, bony scales the outside of which were covered by a layer of shining enamel. The anterior pair of the paired fins is approaching the condition in the Dipnoans, the archipterygium.

Holptychius, from the same locality and horizon as the last, is peculiar in that even at that early date it had developed the cycloidal, horny scales of the modern fishes, both the anterior and posterior paired fins are archipterygial in structure and the caudal fin has become nearly diphycercal by the fusion around the end of the body of the dorsal fins, the caudal and the anal. *Eusthenerpeton*, from the Devonian of Canada, is very similar to *Holoptychius*.

Diplurus, from Triassic of New Jersey, and *Undina*, from the Jurassic of England, present the last stage in the development Crossopterygians. They show an amount of specialization that indicates the extent to which the group had developed and the necessity for adaptation by its members to the most peculiar conditions to maintain an existence. *Undina* was short and very broad. The tail is especially broad and presented a very peculiar appearance, as the end of the spinal column extended beyond the broad psuedo-caudal fin formed by the posterior dorsal above and the anal below. The centra of the vertebræ are still unossified and the bases of the fins are reduced to single pieces of bone. In both this form and *Diplurus* the air bladder was ossified to a considerable extent so that it is preserved in the cavity of the body. *Diplurus* was greatly shortened in the body

by the enormous development of the psuedo-caudal fin, formed as in the case of *Undina* by the posterior dorsal above and the anal below, with the end of the vertebral column extending out beyond the two in a slender fin. The skull was relatively enormous and the jaws entirely edentulous.

Coelacanthus, from the Carboniferous of Ohio, is another of the highly-specialized Crossopterygians. The fins, scales, and general contour of the body is that of a modern bony fish, and it is only upon close examination that the fins were found to be of the archipterygial type and the caudal fin formed in the same way as the same fin in *Diplurus* and *Undina*.

The Actinopterygians are separated into two groups, the *Chondrosteans* and the *Teleocephali*. The first of these groups is very similar in many of its characters to the Crossopterygians, the most important difference and the one that marks the separation of the two greater groups is the structure of the fins. Instead of the lobate, or archipterygial type of fin with the well-developed basals and the symmetrically-arranged radials and fin rays, the basals have almost entirely disappeared and the fin has developed the monoserial structure, *i. e.*, the basal supports are confined to the most proximal part of the fin, and the rays are developed on one side only of the supports.[1] The skeleton is still cartilaginous and the scales are bony and covered with enamel.

Elonicthys, from the Permian of Europe, is a typical one of these forms, the body was somewhat elongate and the scales were narrow. *Eurynotus* from the Calciferous limestone of Scotland, *Cheirodus* from the Coal Measures of Scotland, and *Microdon* from the Jurassic of France, exhibit stages in the gradual development of a great vertical expansion of the body with an attendant shortening and flattening. In the last form there were developed flat crushing teeth instead of the sharp, conical form.

Aspidorhynchus, from the Jurassic of Solenhofen, was an elongate form much like the modern garpike in appearance

[1] See Fig. 3. Ichthyopterygium.

The body was protected by large enameled scales, and the head terminated in a long and sharp rostrum.

Palæoniscus is one the most important of the fossil *Chondrosteans*. It has a remarkable time range extending from the Palæozoic to the Mesozoic and developed a very large number of species. It is supposed to be the form that stands nearest to the ancestral type connecting the modern garpikes and the sturgeons.

These forms seem to have culminated in the modern sturgeons, in which the scales have almost entirely disappeared. In *Acipenser* a few rows of large dermal, enameled plates is all that is left, while in such forms as *Polyodon*, the spoon-billed catfish, the skin is entirely naked.

A second group of the *Chondrosteans*, developed mostly in the Mesozoic, had much more the appearance of the pure bony fish. The scales were small and rounded, and the fins are similar in shape and arrangement to some of the Teleocephali. The bones are calcified and the tail is nearly homocercal, but the vertebræ are still unossified and the notochord is prominent. The modern *Amia*, dogfish, is a surviving member of the group. Among the fossil forms are *Caturus*, *Megalurus*, and *Leptolepis*, from the Jurassic of Solenhofen. The first two of these are important in showing the formation of the vertebræ from the gradual development of bone in the centrum starting from the bases of the upper and the lower arches. In the first two of these forms the base of each arch is joined to a half-moon shaped element that is broad at the base and comes to a point at about the center of the centrum, the two together forming a ring that surrounds the notochord. In *Eurycormus*, from about the same horizon as the last, the same condition prevails in the vertebræ of the dorsal region, but in the tail the wedge-shaped half-moons are completed into bony rings and each vertebra is represented by two of these rings. (A condition that will be found of great interest in the consideration of the morphology of the vertebræ of certain of the amphibia.) The beginning of the process of forming the bony vertebræ by the growth of the

peripheral portion of the ring is seen in the more primitive forms, *Microdon* and *Pycnodus*. In the first of these the bases of the arches are expanded and terminate in rounded and flattened processes that cover the sides of the notochord to a considerable extent, but do not meet in the middle line. In the second form the bases of the arches are more expanded than in the first and the edges of the expanded portions are serrated so that they interlock both with the ones immediately before and behind them and with the one on the opposite side of the notochord.

There have been mentioned here, of course, only the forms that show to some extent the modifications and the lines of development along which the Ganoids traveled. The waters of the Mesozoic lakes and oceans were swarming with members of the group that presented almost as many varieties of structure and form as do the modern bony forms. Because of the strong, interlocking, enameled scales the whole body of the fish is commonly preserved, but the internal skeleton is much less commonly available, so that the most of the forms are known from characters of the scales and the position of the fins, both of which characters are, to a certain extent, unsatisfactory and unreliable.

The *Teleocephali*, the group generally known as the Teleosts, seem to have appeared at about the beginning of the Mesozoic time though it did not reach a great degree of development until near the close of that period and during the Tertiary time. The members of this group differ from the other forms of fishes in the complete calcification of the bones of the body and the nearly complete loss of the notochord by the development of the solid vertebræ which divides it up into intervertebral segments. The scales are horny and rounded, loosely attached to the skin and overlapping in the style of shingles. The fins are formed almost entirely by the dermal fin rays, the basals, and the radials being greatly reduced. Dean says, p. 167: "Fins are dermal structures, their ancient basal supports hardly to be distinguished; the primitive tail structure is so masked by

clustered and fused elements that its heterocercy is scarcely apparent. In short, the most widely modified conditions can be shown to exist in Teleosts in almost every structural character, as in gills, teeth, opercula, circulatory and urogenital organs, sensory structures and nervous system. They have evidently been competing keenly in the struggle for survival, for in every detail of form or structure the most varied conditions exist. In addition to these structural adaptations of the Teleosts, changes in coloration have been rendered possible by the transparency of their scales; and in their different families these changes have taken place often with striking results." It is impossible to go into the forms of the *Teleocephali*, for they are so many and varied that there is no outline even, that the limits of the purpose of this paper would permit. A study of the fossil Teleosts would be practically a study of the osteology of the recent forms.

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E. C. CASE.

EDITORIAL.

Editors Journal of Geology:

My attention has been called to a footnote, appended by one of your number, to a notice of mine, relating to Zirkelite, which note reads as follows: "The prior use of the name *Zirkelite* is certainly established, but it is a question how far a petrographer is justified in stigmatizing the name of a fellow-worker by attaching it to an indefinitely decomposed and ill-defined rock." (JOURNAL OF GEOLOGY, 1898, Vol. VI, p. 200.)

It would seem but common courtesy for another "fellow-worker" to ascertain the truth of his words before he takes advantage of his editorial position to publicly brand another as guilty of an action so low that it ought, if true, to forever ostracize him. I have differed on some points from Professor Zirkel, although in far many more I agree with him. It would seem that my writings prove that I have the courage to openly and honorably express my convictions, and that I do not have to resort to any such vile and disreputable tricks as that your associate plainly but falsely charges me with. I should despise myself if I did, and should expect to be shunned by all decent men. My warfare has ever been open, frank, and honorable, and I have never descended to personal spite and secret efforts to injure another. My contentions have been for what I honestly believed to be the truth, and when I have been shown to be, or found that I was, mistaken I have never hesitated to publicly acknowledge it. I have never taken difference of opinion as any cause for personal ill will, nor have I ever seen any reason why parties thus differing should not be the best of friends.

I gave the name Zirkelite to show my respect and esteem for the honored name of Zirkel, and to prove that, on my part

at least, there was nothing except the kindest of feelings towards him. Everyone who has worked in the field to any extent amongst the older basaltic rocks, ought to know that specimens of Zirkelite can be collected by the thousands, and that the rock is no more "indefinitely decomposed and ill defined" than are the great majority of the rocks designated by specific names, and that it is more common than many of them.

If my fellow-workers will give the name decent treatment, the rock will perpetuate the great name of Zirkel when his work and that of all of us shall have been nearly or quite forgotten in the bright light of future progress. I ask you, as gentlemen, to give my absolute and unqualified denial of the truth of your associate's statement just as wide and public a circulation as you have given to his outrageous and unjustifiable libel.

Very respectfully yours,

M. E. WADSWORTH.

MICHIGAN COLLEGE OF MINES,
Houghton, Mich., June 14, 1897.

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AN error was introduced in the scale of the map facing p. 250 of the last number of this JOURNAL in the photographic reduction for which the author was not at all responsible. The scale should have read: Horizontal, 1 inch = 3 miles. Vertical, 1 inch = 3000 feet.

Reviews.

VAN HISE'S "PRINCIPLES OF PRE-CAMBRIAN GEOLOGY."

For some years investigators and teachers of dynamic geology have needed a revision of the theories of Dana, Fisher, Reade, Dutton, Kelvin, and others, with reference to rock deformation. The publications of Van Hise are a contribution to such a revision, and other articles in preparation by him may probably summarize existing knowledge and current theory in a form, which will be a material advance.

By training, experience, and bent of mind, Van Hise is fitted for the task. As assistant and successor to Irving in the geologic investigation of the Lake Superior iron region, he has solved the most difficult problems of the older rocks. In microscopic petrography of the crystalline schists and allied formations he is a leading authority. In obscure stratigraphy and complex structural relations he has had much experience. His base of observation has been broadened to include all important districts from the Pacific to the Atlantic, and the classic localities of Europe.

The *Principles of Pre-Cambrian Geology* is a work intended "(1) to give a partial discussion of principles applicable to geological work among the pre-Cambrian rocks of North America, and (2) to give an historical account of the North American pre-Cambrian, and to point out the principles illustrated in the various regions."

In Part I the author discusses (1) movements of rock materials under deformation, (2) analysis of folds, (3) cleavage and fissility, (4) joints, (5) faults, (6) autoclastic rocks, (7) metamorphism of the sedimentary rocks, (8) metamorphism of the igneous rocks, (9) phenomena of stratigraphy.

Part II describes the facts of historical geology in general for the Archæan and Algonkian periods, and in particular for ten districts of the United States and Canada in which rocks of these ages occur. There is an appendix on "Flow and Fracture of Rocks as Related to

Structure," by Leander Miller Hoskins, who treats the subject by mathematical analysis.

In 1878 Heim published his discussion of "Umformung durch Bruch and Umformung ohne Bruch."[1] It was necessary less than twenty years ago that he should present an elaborate argument to show that without the action of any softening agent rocks might be deformed without fracture under appropriate mechanical conditions. He had seen and understood qualitatively the facts of folded strata. Van Hise carries the interpretation to quantitative expression in terms of pressure per square inch dependent on depth beneath the earth's surface. Following Heim, and going further than he did, Van Hise formulates three principles:

(1) Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture. (2) Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage. (3) Rocks buried to such depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.

Under the assumption that rocks are porous, and that, therefore, interstitial spaces at a depth are sustained by a column of water extending to the surface, the author calculates, from formulas furnished by Hoskins, that no cavity can exist permanently in even the strongest rock at depths of 10,000 meters or more below the surface. As the development of cavities is a feature of fracturing, deformation with fracture is not possible below that depth. That zone in which deformation occurs without fracture is designated by Van Hise the zone of flowage.[2]

Since rocks vary in strength the depth of the zone of flowage beneath the surface is variable, and where rocks of unequal strengths are interbedded the harder may be in the zone of fracture, the softer in the zone of flowage. It follows that there is a broad zone of fracture

[1] Mechanismus der Gebirgsbildung, Vol. II, pp. 3–75.

[2] Since the paper reviewed was written, Van Hise has described much more fully the minute phenomena of the zone of flowage (Bull. G. S. A., Vol. IX, pp. 295–312). According to his recent conclusions, the deformation in this zone includes both microscopical granulation of the mineral particles and their recrystallization. Therefore in this zone he recognizes microscopic fractures and openings.

and flowage intermediate between an upper zone, in which all rocks fracture, and a lower zone in which all flow.

Gilbert and Dutton, as well as Heim, had anticipated the conclusions of Van Hise in the general recognition of a zone of fracture and a zone of flow, but Van Hise first describes clearly the phenomena of a zone of combined fracture and flow, with which geological observation of structure has chiefly to deal. He contributes also a closer analysis of the phenomena in the uppermost and lower zones. The development of autoclastic breccias, the production of folds by opening of radial joints due to fracture, the association of deformation by fracture and without fracture in the same zone, the adjustments of form by which strata yield to folding, the disappearance of folds in depth, and finally the phenomena in the zone of flowage, are clearly and critically discussed.

The analysis of folds is based upon a classification by de Margerie and Heim, published in 1888, but their ideas are amplified, and a comprehensive classification capable of including all types is developed by the author's recognition of the complex nature of folds. The author's primary classification divides flexures into simple, composite, and complex folds. Simple folds are single anticlines and synclines, which are subclassified in the usual manner as upright, overturned, or recumbent, and as symmetrical or unsymmetrical folds. But Van Hise recognizes that every fold of any magnitude is complicated by minor folds and each of these again by still smaller folds, and so on to microscopic plications of the *n*th order. When thus considered, the major fold may be termed composite. Composite folds of the first magnitude were described by Dana as geosynclines and geoanticlines, and these, as Van Hise points out, are due to combined action of gravity and lateral thrust. In the discussion of composite folds they are classified as normal and abnormal, and the basis of classification is the direction of convergence or divergence of the axial planes of the secondary folds. Thus in a normal anticlinorium the axial planes of the secondary folds converge downward and diverge upward, whereas in an abnormal anticlinorium the axial planes of the secondary folds converge upward and diverge downward. No exception can be taken to this classification as a matter of fact, but as a scheme adapted to instruction or to practical discussion it may not be generally useful, because the mind is speedily confused by the repetition of the terms of upward and downward convergence as applied to anticlinoria and

synclinoria of the various normal and abnormal types. Even one tolerably familiar with the aspects of folds must stop to draw a diagram before he can remember what the definition of a given type is.[1]

A definition of normal and abnormal folds, which may appear simpler, may be based on relative dips and depths of folds. It depends upon a law stated by Heim,[2] which is that from a normal anticline a stratum dips more steeply toward that syncline into which it descends to the greater depth. Thereon we may phrase the definition:

A normal fold is one in which the steeper dip is toward the deeper syncline of the same order, whereas an abnormal fold is one in which the steeper dip is toward the shallower syncline of the same order.

This definition has one advantage over that stated by Van Hise. It is related to the initial conditions which determine the positions of folds and their normal or abnormal development, whereas the axial planes are mathematical conceptions only, without actual existence. The relative depths of synclines and the steeper dips are frequently determined in the initial stages of development of folds, and persist as controlling conditions. In any littoral zone the steeper initial dip is usually from the land toward the sea. The resulting steeper dip after deformation holds a corresponding relation.[3]

Van Hise introduces a new use of the common term "monoclinal," in that he applies it to describe "that structure of a mountain mass in which the axial planes of all folds are inclined in the same direction." Discussing "monoclinal structure" he discriminates between overthrust folds and underthrust folds as follows, page 621:

"In monoclinal structure the force, and consequently the movement of the strata have usually been supposed to be more largely from one direction than from the other, and the axial planes of the folds have usually been regarded as dipping toward the force."

After reference to the ideas of H. D. Rogers, Van Hise continues, page 622:

[1] It has been suggested to me by Mr. L. C. Glenn that a general expression of Van Hise's law of normal folds may be phrased as follows: In a normal fold the axial planes converge centrically with reference to the arc which corresponds to the curvature of the anticlinorium or synclinorium. In an abnormal fold the axial planes converge eccentrically.

[2] Op. cit., pp. 231–233.

[3] Conditions of Appalachian Faulting, WILLIS and HAYES, Am. Jour. Sci., Vol. XLVI, October 1893.

"Folds thus produced by upward differential movement may be called 'overthrust folds.' The axial planes dip toward the effective stress, hence *overthrust folds are those in which the axial planes dip toward the force producing them.* While the development of overthrust folds is the general law, it may not infrequently happen that under favorable conditions the beds or formations may be thrust forward and downward. The folds thus produced by downward differential movement may be called 'underthrust folds.' The axial planes dip away from the effective stress, hence *underthrust folds are those in which the axial planes dip away from the force producing them.*"

The idea of Rogers that deformation proceeded by a wavelike motion, which, in the case of the Appalachians, emanated from the Atlantic region, is firmly fixed in geology without being sufficiently justified by facts. Appalachian structure in many districts presents a monoclinal inclination toward the southeast. If it be overthrust, the effective force operated from that direction. If it be underthrust, the effective force acted from the northwest. There is nothing in the monoclinal relations of folds which will determine that alternative. Theoretically, the geologist is at liberty to infer overthrust in preference to underthrust or *vice versa*, but an hypothesis of the origin of force based upon that inference is of no value. The analysis given by Van Hise leads him to the conclusion that the monoclinal folds and cleavage which prevail in the crystalline areas of the Appalachians are due to an effective force from the southeast, but that conclusion cannot be considered as demonstrated. Indeed, other geologists approaching the problem from a different point of view are justified in reaching the reversed conclusion.

It may be suggested that compression, which causes strata to fold, is a force of gradual accumulation, that is, of such slow growth that the pressure is transmitted through a rock-mass of indefinite extent until movement ensues. Such movement may probably begin at a point determined by local conditions, and may continue in a direction determined by the least resistance either as an overthrust or an under-thrust. In that view the more effective force is simply that which is opposed to the less effective resistance, and the hypothesis of a wave-like influence emanating from a distant source is unnecessary.

Complex folds are defined by Van Hise as those canoes, basins, and domes which result where two sets of folds intersect each other.

The two sets of folds may be produced simultaneously or at distinct epochs by two or more thrusts in diagonal directions or at right angles. Any two diverse thrusts inclined to each other may be resolved into two forces at right angles, which will produce complex folds; if, however, the divergence of the two thrusts is moderate, their effect may be combined to produce a simple system of parallel folds.

Of the two thrusts producing complex folds, one is usually the major thrust, the other the minor thrust, and the system of composite folds to which one or the other gives rise may be described accordingly as the major or the minor system. The length of canoes is proportioned to the difference in power between the major and minor thrusts. If the major thrust greatly exceeds the minor, the complex folds will be long, narrow, and parallel; if the two thrusts are nearly equal the folds will be domes and basins.

As an example of complex folds Van Hise refers to the Appalachian region. The reference, perhaps, requires qualification to modify its general application to the whole province. Districts of New England and North Carolina do exhibit complex folds which are markedly developed in the direction of the minor as well as of the major thrust, but in the Appalachian Valley region from New York to Alabama the folding scarcely appears to be complex. Van Hise cites the undulatory pitch of the axes as evidence of a pressure from northeast to southwest. The pitch is to some degree due to variations of initial dip and the depression of synclines in folding. There is no crenulation of the major strikes such as might be expected to result from a transverse thrust. If this zone of typical Appalachian structure shall be shown to be complex in the sense in which Van Hise defines the term, there will be good reason to assume that complex folding is the general rule. This may probably be so.

Van Hise's extensive experience in the study of complex structure enables him to suggest practical methods as to the manner of determining whether the rocks of the district are complexly folded and in what manner. These suggestions relate to the manner of making certain necessary observations, which he sums up as follows:

1. "Determine the strike and dip of the strata at the given point. These give the resultant position of the strata as tilted by the force of folding in both directions."

2. "Determine the direction of the pitch of the axes of the major folds. The first is the direction of dip, and the second is the amount

of dip of the minor or cross folds. The average strike is therefore determined."

3. "Determine the direction and pitch of the axes of the minor folds. The first is the direction of dip, and the second the amount of dip of the major folds. The average strike is therefore also determined."

Van Hise correctly observes that of these three observations the first is the only one ordinarily taken, and it is the one of least importance in regions of close complex folding. It becomes obvious in considering his practical suggestions that a thorough knowledge of the physiography of the region and the relation of relief to structure is quite as important for the solution of complex folds as is a knowledge of the rocks.

Concluding the section relating to folding, Van Hise considers the value of differential folding as an evidence of unconformity, when not sustained by other phenomena. A discordance in the flexures of two adjacent formations is only to be absolutely relied upon as evidence of unconformity when the structural discordance is so marked that the earlier series exhibits a relatively complex structure as compared with that of the later series.

In Section III Van Hise considers cleavage. He grasps hypotheses of the origin of cleavage advanced by other geologists from Phillips to Becker, discriminates between them, amplifies their basis of fact by his own extensive observations of the crystalline schists, and states those conclusions which he finds valid. He defines *cleavage* in a strict sense "as a capacity present in some rocks to break in certain directions more easily than in others." This use of the term is that in which it is applied to minerals. He distinguishes fissility as a phenomenon secondary to cleavage, fissility being "a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature."

Citing microscopical study of cleavable slates and schists, Van Hise concludes (page 635) that:

"Rock cleavage is due to the arrangement of the mineral particles with their longer diameters or readiest cleavage, or both, in a common direction, and that this arrangement is caused, first, and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and third, and of least importance, by the rotation into approximately parallel positions of random original particles."

From these observations follows the inference that cleavage develops in a plane normal to the pressure. The grounds for this inference are discussed at some length and the author's opinion is finally stated (page 639):

"I therefore conclude from analysis, from experiments upon viscous and plastic bodies, from observations in the field, and from studies with the microscope, that I am justified in the statement that the secondary structure of a rock which is deformed by plastic flow develops in the plane normal to the greatest pressure, and that this structure is true cleavage."

From the observed parallelism to the inferred normal relation to pressure is a step in hypothesis. To this extent the conclusion falls short of demonstration, but it is in accord with the opinions of eminent students on cleavage, and is supported by mathematical analysts, with one marked exception. The exception is Mr. Geo. F. Becker.

It has been maintained by Becker that cleavage always develops in two shearing planes at angles to the pressure. His method of arriving at this conclusion may best be indicated by a quotation from his article:[1]

"In the following pages the attempt will be made to develop all the manifestations of uniform or homogeneous finite strain in rock-masses regarded as isotropic, exhibiting viscosity and capable of flow, which can be elucidated without assuming a law connecting stress and strain. For this purpose finite strain must first be discussed by itself; then it must be considered just how far the relations of stresses are capable of coördination with those of strain. The influence of viscosity and solid flow must next be shown. Readers willing to assume that these subjects have been logically treated will probably skip them and proceed to the geological applications which follow. Finally, the results will be compared with actually observed phenomena and with the experiments which several investigators have made on slaty structure."

The method followed by Van Hise is that of induction from the facts, whereas Becker pursues that of deduction from general principles. Van Hise does not deny the validity of Becker's reasoning nor its general application. He describes the development of fissility and jointing in the zone of fracture as in accordance with Becker's view. But he con-

[1] Finite Homogeneous Strain, Flow, and Rupture of Rocks, by G. F. BECKER, Geol. Soc. Am., Vol. I.V, 1891, p. 16.

cludes that in the zone of flow another process is effective to product cleavage; namely, special orientation of minerals and particles.

Fissility is defined by Van Hise as a parting of a rock along shearing planes, which corresponds with the structure described by Becker as cleavage. It is obvious that a capacity to part in a certain plane (Van Hise's cleavage) may often coincide with an actual parting developed later. If the capacity to part be a structure developed in the deep zone of flow, it is most probable that the actual parting should be developed in rising through the zone of fracture, as any rock mass must to become accessible to our observation. Hence arises the opportunity for confusion of the two structures, according to Van Hise, but discriminating the one from the other he concludes that: "Fissility developing in the shearing planes is usually secondary to cleavage which developed in the normal planes."

The relations of cleavage and fissility to bedding and to folds are discussed at length, and the value of these structures as criteria for determining unconformities are stated and limited.

With reference to joints Van Hise's discussion is along lines logically consistent with his views of folding and also of fissility. Tension joints may be produced radially to the curvature of folds; this phenomenon he rightly considers important as a means of accommodation to curvature in the zone of fracture. Compression joints develop in shearing planes, usually in two directions, and when associated with simple folds generally parallel to the strike. When folding is complex different sets of shearing plains may correspond to strike-joints and dip-joints, but the association of three or more joint systems may probably be the result of several orogenic movements.

Faults also are classified as tension faults and compression faults, but recognizing the dominant influence of gravity or of thrust respectively, Van Hise well prefers to distinguish them as "gravity" faults and "thrust" faults. The former is equivalent to the old term "normal," the latter to the inaccurate designation "reversed" fault.

In discussing the relation of faults to folds it is stated that under moderate load thrust faults may result as clean cut fractures, whereas under greater load they may be associated with overfolds, and at still greater depths overfolds may develop without thrust faults.

"This statement might be well supplemented by the further explanation that folds may give place to thrusts on diagonal planes in the deep zone of flowage. Two conditions are essential to folding;

first, that the stratum shall be sufficiently rigid to transmit a maximum stress in a definite direction; and second, that movement on bedding planes shall afford a means to adjustment to curvature. It is an open question how far these conditions are effective in a deep zone of flow. In the opinion of the reviewer neither of them exercises a dominant influence. Distinctions of stratification may become insignificant under excessive pressure, and great friction on bedding planes may prevent accommodation, and the mass may be deformed by dislocation in the diagonal planes. This is illustrated in model J, Plate XCIII, stages *f* to *k*, "Mechanics of Appalachian Structure." The accommodation of the soft material to shortening in one direction and elongation in another is there accomplished by the reciprocal displacement of wedges, which are defined by planes diagonal to the applied force. This explanation is briefly suggested by Van Hise in a subsequent paragraph on the depth of the zone affected by faults, but he fails to emphasize the idea that while thrusts developed in the zone of fracture pass into folds below, folds in turn may be replaced by thrusts at still greater depths. The relation is important."

Comparing the effect of few great structures with that of numerous small ones, Van Hise concludes:

"The average deformation of a region may be the same whether it be by a few great faults with little or no fissility, by more frequent lesser faults with or without fissility, by faults and overfolds with or without both cleavage and fissility, or by folding with or without faults and cleavage; also that there is every gradation between faulting and fissility, and probably every gradation between faulting and cleavage."

In Section VI, Van Hise discusses dynamic breccias and pseudo conglomerates under the generic term of "autoclastic" rocks, which was first used by H. L. Smyth. The development of autoclastic rocks is limited to the zone of fracture and they are not of common occurrence in strata younger than the Cambrian. But where they occur in rocks which have undergone repeated disturbances the resulting dynamic breccia may so resemble a basal conglomerate as to lead to an erroneous inference of unconformity. In the discussion of these cases Van Hise inadvertently illustrates with what remarkable care and patience the geologic study of the Marquette district has been pursued.

Metamorphism is treated in sections VII and VIII, with the purpose "briefly to sketch a few of the more important processes which have

affected large areas of the pre-Cambrian rocks of North America." The author recognizes pressure, heat and chemical affinity as the prominent forces producing metamorphism. When pressure is resisted by rigidity, *i. e.*, produces only molecular motion, the result is static metamorphism; when pressure passes into mass motion the result is dynamic metamorphism. The chief processes considered are consolidation, welding, cementation, injection, metasomatism, and mashing.

In discussing cementation and injection the author takes up the origin of pegmatites and says:

"It seems to me that to adequately explain all the facts of pegmatization described in various regions of the world, we must conclude that all three processes have been at work — in some cases igneous injection, in some cases aqueo-igneous action, and in other cases pure-water cementation, and in still others combinations of two or all of these processes. It is further believed that there may be no sharp separation, but, on the contrary, all gradations between the three — that is, it is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. In other words, under proper conditions water and liquid rock are miscible in all proportions. From the water solutions true impregnation or cementation would take place; from the rock solutions, true injection. Pegmatization may comprise these and the intermediate processes."

Metasomatism is described with reference to (1) "alteration of original mineral particles, (2) minerals produced by alterations, and (3) texture of rocks produced." The brief statement of facts familiar to petrographers suggests also broader aspects of comparative petrology.

"Mashing is a term here introduced with a specific meaning. It is used to designate by a single word that complex process which involves shortening without change of volume, or simple shearing, or a combination of the two. Mashing implies all the other special processes of metamorphism."

Having thus considered in general the processes of metamorphism, Van Hise classifies metamorphic sedimentary rocks according to those processes which have been particularly effective in the development of each class. The enumeration of rock types in relation to conditions affecting their development is particularly valuable.

Metamorphic igneous rocks are treated separately, though briefly, but the means of discriminating between originally sedimentary and originally igneous rocks are discussed with the insight due to broad observation. The difficulties of discrimination are suggested in the following statement:

"It has been seen on previous pages that a large number of kinds of schists and gneisses may be produced by the metamorphism of sedimentary rocks; also it has been shown that similar crystalline schists may be derived from igneous rocks. It is further certain that a schist or gneiss may be derived partly from sedimentary and partly from igneous rocks. For instance, a metamorphosed fissile sedimentary rock, such as mica-schist or mica-gneiss, may be injected in a complicated way parallel to the planes of schistosity, and thus produce a banded gneiss, part of which is igneous and part of which is sedimentary. The rock may be predominantly of either one of these materials. If the injected sedimentary rock be subsequently folded, this will produce differential movements parallel to the banding, and the igneous and aqueous bands may be merged into one another and have structures so similar that it is impossible to determine what part of the rock is igneous and what part aqueous. The Manhattan schists of southeastern New York, and especially near Long Island Sound, are a perfect illustration of a gneiss produced by the extreme metamorphism of a sedimentary schist and the subsequent parallel and cross injection of granitic material.

"From the foregoing it is clear that an inseparable schist or gneiss formation may be produced from altered intrusive rocks, from altered lavas, from altered tuffs, from altered sediments, and from any possible combination of two or more of these.

"Doubtless, in regions in which the gneisses are of a very complex character, a number of the processes mentioned in the previous pages, and possibly others unknown, must be united in order to explain all of the phenomena."

Stratigraphy, *i. e.*, the sequence of formations, is deduced for pre-Cambrian rocks from observations of the phenomena of structure and metamorphism and other relations in detail. It thus becomes an inference instead of being a primary fact of observation, as it may be in rocks which are less disturbed. Van Hise, therefore, gives stratigraphy a logical position at the close of his discussion of principles. The evidences of stratification which are obvious in unaltered series

may be so obscured in older rocks as to be determinable only by the closest observation. Hence, bedding, ripple marks, basal conglomerates, and phenomena indicating unconformity afford material for extended consideration.

This review would be made too long by detailed references to the second part of the "Principles," which treats of the historical geology of the pre-Cambrian time. The discussion is arranged according to districts and for each district the principle most saliently illustrated is emphasized. This part of the book constitutes a valuable summary of existing knowledge and a convenient and reliable reference.

The style of the author is the expression of complete knowledge of his subject, combined with exuberance of thought. Another great writer, whose works are characterized by brilliancy and clearness, recently said: "When I undertake to write a book I endeavor first to see what I can exclude from it, and after the process of rigid exclusion I carefully arrange the surviving ideas even to the order of paragraphs before I write." The thoughts which rush upon Van Hise are related in so many directions that many associations of the idea seek expression at once. His book would be easier to read and not necessarily less accurate, if the thought were stripped. The logical analysis is consistently carried out for all the major headings, but it is not adequately extended to the paragraphs and sentences. Nevertheless, a thorough study of the work leaves a profound impression of the earnest purpose with which it has been conceived and of its value as a contribution to one of the most difficult branches of geologic science.

BAILEY WILLIS.

Topographic Atlas of the United States. Physiographic Types by HENRY GANNETT. Washington: U. S. Geological Survey, 1898.

The enlightened policy adopted by our national Geological Survey of encouraging as wide a use as possible of the material gathered at great expense receives a new and welcome illustration in the publication of the first folio of the above named series. It presents ten maps as "illustrations of some of the simplest and most characteristic types of topography to be found in those parts of the United States which have been thus far mapped. Succeeding folios will illustrate more complex forms." The origin of the atlas was in a proposition of the

director of the survey to publish "an educational series of folios, for use wherever geography is taught in high schools, academies and colleges," authority for such publication having been granted by Congress in an act approved March 2, 1895.

The following titles represent the contents of this first folio: A region in youth: Fargo, North Dakota-Minnesota. A region in maturity: Charleston, W. Va. A region in old age: Caldwell, Kan. A rejuvenated region: Palmyra, Va. A young volcanic mountain: Mt. Shasta, Cal. Moraines: Eagle, Wis. Drumlins: Sun Prairie, Wis. River Flood Plains: Donaldsonville, La. A fiord coast: Boothbay, Me. A barrier-beach coast: Atlantic City, N. J. It may well be claimed that no more important, useful, or interesting series of maps could be selected for the elementary exposition of physiographic types.

It must be most encouraging to teachers of geography to find so efficient an ally as this series of folios will prove. Such a publication gives an authoritative stamp, such as has not yet been received in any other country, to the methods of modern physiographic description. It recognizes the essential importance of stage of dissection and movement with respect to baselevel, as a means, not merely of explaining the past history of a region, but of describing its present form. Withal, the text is written in a clear and simple style, certainly within the reach of even those teachers of other subjects upon whom the unexpected responsibility of having to teach geography so often falls. The few technical terms that are employed are fully explained. The relation of form to conditions of settlement and movement are touched upon. The later numbers of the series will be awaited with much interest.

Where so much is good, it gives regret to find the text of one map open to adverse criticism. The account of the Booth Bay sheet needs revision regarding glacial action. The region is described as having been for a long time "subjected to aqueous erosion, which brought it to a condition of old age with gently flowing streams, smooth slopes, and rounded divides." Upon such a surface advanced the Great Northern Glacier, and proceeded to modify it. It is difficult for the reader of this part of the text to avoid concluding that when southern Maine was thus "planed down by aqueous erosion," it was about as flat as the plains of Kansas—the type of old age—and that its marked relief today is the result of glacial erosion. There is, on the contrary, good reason for believing that since the greater part of New England was

brought to a condition of old age, it has been rejuvenated and more maturely dissected than the Piedmont upland of Virginia, the type of renewed dissection in a second cycle. The ice-sheet therefore advanced over a region of distinct hills and valleys, not over a peneplain. The implication that the ice-sheet was an effective agent of destruction is confirmed on reading that the traces of glacial action "here consist mainly of features of erosion. But little matter was deposited by it, that little consisting of what is known as 'erratics,' or granite bowlders, which are scattered freely over the country. . . . . A great deal of erosion, however, was done by the ice-sheet. It searched out very keenly the soft spots in the granite surface of the country and scoured them away, leaving depressions and, between such depressions, rounded hills of granite. . . . . All of the soil or disintegrated rock was scraped away, leaving the granite bare; hence it is that the soil covering of southern Maine is very thin, for it has been derived mainly from the disintegration of rocks since the passing of the glacier." Apart from the implication that the hills today result from the glacial excavation of depressions between them, and from the implication that granite is the only kind of rock in this region whose linear ridges and fiords give so strong an indication of foliated or stratified structures, it is unfortunate that the common veneer of till, the relatively plentiful deposits of washed gravel and sand, and the important cover of marine clays in the valley floors of southern Maine should pass unnoticed. The farmers of that region very rarely depend on soil of postglacial weathering. The rocky ridges with a thin soil, partly of glacial drift, partly of postglacial weathering, are left in uncultivated forests and woodlots.

It is further to be regretted that, after showing by the first four types that time is an important element in geographical description, no sufficient mention is made of the element of time in connection with the two examples of shore-line features. It is of course recognized that the irregular coast line of Maine is a result of the partial submergence of a rugged land; but no consideration is given to the evidence that the submergence is recent; so recent that wave action has not yet cut back the headlands, and that river action has not yet filled up the bay heads. Hence the account of shore lines is not homologous with that of land surfaces, in which the stage of advance reached by destructive processes is carefully considered. The opportunity for teaching an important principle in the evolution of shore lines is thus lost.

W. M. Davis.

Volcanoes of North America : A reading lesson for students of Geography and Geology. By ISRAEL C. RUSSELL. The Macmillan Company, New York, 1897.

The object of this book is plainly stated by the author in the introduction — "It is to the character and history of this vast volcanic belt, reaching from the tropical shores of Costa Rica to the western extremity of the bleak and inhospitable Aleutian Islands, that the attention of students of geology and geography is here invited. The object of this book is to make clear the principal features of volcanoes in general, and to place in the hands of students a concise account of its leading facts thus far discovered concerning the physical features of North America which can be traced directly to the influence of volcanic action." Its title indicates that it is not intended to be a thorough treatise on the subject, but rather a readable account of the leading features. It will undoubtedly prove satisfactory to those who read it with this understanding. It has gathered together in an attractive form many scattered descriptions of the volcanoes and volcanic mountains of North America, and has placed the student in the way of finding the original accounts. It will excite interest in the volcanic phenomena to be found on this continent and will perform a helpful mission. The arrangement of the material is good and the interest of the reader well sustained by the general style. The illustrations are valuable and attractive.

There are, however, numerous evidences of carelessness in the work which are to be regretted. The section on the Characteristics of Igneous Rocks is open to severe criticism. Its definitions are crude and misleading, and incorrect arguments are presented in several instances. The section should be carefully revised.

The effort to connect the active volcanoes of Central America with those of the Aleutian islands, as though they constituted one chain, is not justified by the facts; the former being much more closely connected with those of the Andes, and the Alaskan volcanoes with those of the Japanese islands.

The descriptions of the volcanoes within the United States are somewhat unsatisfactory since they bear little relation to their relative importance. Considerable space is devoted to detailed descriptions of very insignificant craters in Utah and Nevada, and to the comparatively small volcanoes near Mono Lake, Nev., while much less is given to that of the great mountains, Shasta, Rainier, and other volcanoes of

the Pacific Coast. And no mention whatever is made of the volcanic region of the Yellowstone National Park, a region not only characterized by great diversity of volcanic phenomena, where the influence of volcanic action on the physical features of the region is most marked, but one that is being constantly visited by students and tourists.

The chapter devoted to the theories of volcanic action is good in the main for an elementary treatment of the subject. But some of the reasoning is obscure, especially that with reference to the behavior of absorbed vapors, and the question of their presence or absence from deep-seated and surface rocks. The effort to minimize the effect of steam upon the eruption of lava appears to have been carried too far.

It is greatly to be regretted that defects such as these exist in a book that has so many excellent features to recommend it.

J. P. I.

Revised Text-Book of Geology. By JAMES D. DANA. Edited by WILLIAM NORTH RICE. American Book Company, New York.

The earlier editions of this work are so well known that interest in the present edition is concerned chiefly with the nature of the revision. This had been begun by Professor Dana a short time before his death, but little progress had been made. By request, his former pupil, Dr. William North Rice, completed the work. His aim has been to retain the distinctive characteristics of the book so far as possible and, while bringing it down to the present time as regards its facts, to preserve the known opinions of its author. The editor has endeavored to subordinate his own views to those of the original author, although on certain points, as for example, geographic and climatic oscillations of the Quaternary era, he would have preferred a somewhat different expression. The general plan of arrangement remains unchanged and the omissions about counterbalance the introductions. The zoölogical and botanical classifications previously used were judged to be obsolete and the schemes followed in a majority of the recent manuals of zoölogy and botany were substituted. The theory of evolution finds fuller recognition than in the previous editions. In the treatment of metamorphism the text is considerably modified, especially with reference to the dynamic phases and to the foliated structure of igneous rocks. Otherwise the book presents essentially

the views of science held by the distinguished author in his later years. In the very delicate task of eliminating such errors as the progress of science has developed, and at the same time of deferring almost reverentially to the opinion of the author, Dr. Rice appears to have attained a high degree of success, although some further eliminations of opinions and interpretations which, though not absolutely abandoned by all geologists, have been practically overthrown, might have added value to the work. T. C. C.

Fossil Plants for Students of Botany and Geology, Vol. I, 450 pp., with illustrations. By A. C. SEWARD, University Press, Cambridge, Eng., 1898.

Botanists and geologists both are bound to welcome Professor Seward's work on Fossil Plants, the first volume of which has recently appeared. This book forms one of the familiar Cambridge Natural Science Manuals, and is rather more extensive than the others. It is safe to say that no general work on palæobotany had previously appeared in English that was satisfactory to both botanists and geologists, and very few that were satisfactory to either. Hence it is a pleasure to read in the preface that this book is intended for both botanists and geologists, and thus has to be adapted to both non-geologists and non-botanists, since it is unfortunately true that neither class, as a rule, appreciates the standpoint of the other. The first chapter contains a brief historical sketch of palæobotany in which the author gives special credit to Brongniart and Williamson. Chapter ii gives the relation of the subject to botany and geology. Professor Seward tells how palæobotany has been buffeted about by the geologist and the botanist, the one culling out facts relating to correlation of strata, the other caring only for facts which give hints as to phylogeny and evolution. He pleads for the recognition of palæobotany as a science of and for itself, with its own peculiar problems, viz., the determination of the historical succession of plants in geological time; the delineation of the actual evolution of the plant kingdom, giving light on phylogenetic mysteries; the presentation of the various floral areas of the past, leading up to an explanation of the distribution of plants in the present day; conclusions as to climatic and other conditions in geological time as revealed by the occurrence of certain peculiar plant types and

by anatomical adaptations to environment. The third chapter gives the leading facts of geological history, and is designed for botanical readers. The next chapter discusses the various methods for the preservation of plants as fossils; structure unmodified, as in fossil soils and forests; carbonization; incrustation, as travertine; casts; petrifactions. The relative rarity of plant fossils is due to their soft structure and land habitats. Chapter v is exceedingly interesting and valuable, as it demonstrates the enormous difficulties and sources of error, such as (1) the danger of depending too much on external resemblances, since many forms from algæ up to seed plants may look alike even in modern forms, much more in fossils; (2) fragmental preservation — this is much more common than in animal fossils, and also leads to much more error, since a plant often can be identified only in fruit; (3) decorticated trunk and pith cylinders; (4) resemblance to animals or animal tracks and mineral deposits.

After a chapter on nomenclature, the author takes up the plants by groups. In this first volume he treats only of the Thallophytes, Bryophytes, and some Pteridophytes. Among the algæ there is an abundance of undoubted fossil blue-green algæ, forming deposits of travertine and possibly oölite. Professor Seward thinks that similar forms probably represented the first life of the Algonkian. Because of their siliceous tests there are vast deposits of diatoms, mainly from the Cretaceous on. Of the larger marine algæ those forms are especially preserved which are covered during life by calcareous incrustations, especially the corallines. Many plants of all kinds and many mineral deposits, rill marks, and animal tracks have been referred to the algæ, and especially to the fucoids. Among fungi there are abundant evidences of fossil bacteria, but the higher forms are rare, though found in the Carboniferous and Tertiary. The liverworts and mosses are poorly preserved and difficult to identify. Of the Pteridophytes, the author considers in this volume only the equisetales and sphenophyllales. Both of these groups are abundantly preserved and well known. At the close of the volume is an excellent bibliography.

This work of Seward's has at least three features to commend it that are by no means common to all books on palæobotany. It is extremely cautious in its statements; many forms commonly described are either classified tentatively or omitted altogether. There are not so many startling allusions to high-grade plants in the early ages, but there are more real facts on which to base safe conclusions. Another

valuable feature of the book is that important facts have been culled out from a mass of unimportant material; and by no means least in its commendable qualities is the fact that it is actually readable; even the botanical or geological layman may enjoy it if he cares for such things at all. Everyone who reads the first volume will anxiously await the appearance of the second.

HENRY C. COWLES.

Northward Over the "Great Ice": A Narrative of Life and Work along the Shores and upon the Interior Ice-Cap of Northern Greenland in the years 1886 and 1891–1897. By ROBERT E. PEARY. 2 vols. Illustrated. Frederick A. Stokes Co., New York. 1898.

In these two volumes, embracing nearly 1200 pages, Lieutenant Peary has given a graphic account of his entire Arctic work. The story begins with a reconnaissance of the inland ice of Greenland in 1886. The objects and results of this reconnaissance he summarizes as follows:

Objects. — To gain a practical knowledge of the obstacles and ice conditions of the interior of Greenland; to put to the test of actual use certain methods and details of equipment; to make such scientific observations as may be practicable; and to push into the interior as far as possible. (Paper read before National Academy of Sciences at Washington, D. C., April 23, 1886.)

Results. — Attainment of greater elevation than ever before reached on the inland ice; penetration a greater distance than any white man previously; attainment for first time of the real interior plateau of unchanging snow; determination of ruling characteristics of the inland ice from border to interior (see article in *Bulletin Am. Geog. Soc.*, No. 3, 1887, pp. 286–288); securing an invaluable fund of definite practical knowledge and experience of actual ice-cap conditions and necessary equipment, as well as practical knowledge of Arctic navigation and a familiarity with a considerable extent of the Arctic coasts; inception of ideas of pronounced future value, as odometer, sails, etc. The following deductions: Attacks upon the inland ice should be made at a point as far above level of sea as possible, and where the presence of large and rapidly discharging glaciers indicates a rapid ascent to high elevations in close proximity to coast; party should be *small*, and thoroughly accustomed to snowshoes and ski; surface of inland ice offers imperial highway to east coast, and, in case the ice-cap is coëxtensive with the

land, to the northern terminus of Greenland. Proposal of the following prophetic routes: From base of Noursoak Peninsula to head of Franz Joseph Fjord and return; from Whale Sound to northern terminus of Greenland or intersection of ice-cap with east coast — this route the key to the Greenland problem; from Disco Bay to Cape Dan.

The remainder of Vol. I is occupied by the story of the North Greenland expedition of 1891–2. Most of our readers are doubtless familiar with this famous trip across the northern portion of the great ice-cap, but still they will read this authoritative statement by the explorer himself with fresh interest and satisfaction. The author summarizes the objects and results of this expedition as follows:

Objects. — Determination of the northern limit of Greenland overland; the possible discovery of the most practicable route to the Pole; the study of the Whale Sound Eskimos; the securing of geographical and meteorological data.

Results. — The determination of the northern extension and the insularity of Greenland, and the delineation of the northern extension of the greater interior ice-cap; the discovery of detached ice-free land-masses of less extent to the northward; the determination of the rapid convergence of the Greenland shores above the seventy-eighth parallel; the observation of the relief of an exceptionally large area of the inland ice; the delineation of the unknown shores of Inglefield Gulf; and the imperfectly known shores of Whale and Murchison sounds; the discovery of a large number of glaciers of the first magnitude; the first complete and accurate recorded information of the peculiar and isolated tribe of Arctic Highlanders (Dr. Cook); complete and painstaking meteorological and tidal observations (Verhoeff); sledge journey, which is unique in respect to the distance covered by two men without a cache from beginning to end, and in respect to the effectiveness with which those men were able to handle a large team of Eskimo dogs; corroboration of the opinion advanced that the inland ice offered an "imperial highway."

Vol. II opens with a narrative of the expedition of 1893–4, which is memorable on account of the great equinoctial storm encountered, that appears to have been without a recorded parallel even in that land of terrific gales, and that proved disastrous to the undertaking. Among the subsidiary narratives of special interest are the stories of the discovery of the great Cape York meteorite by Peary and the reconnaissance of Melville Bay by Astrup. In this part are also included a summary of the valuable meteorological observations of Baldwin. Then follows an account of the visitation of the *Falcon*,

the return of the larger part of the party, the voyages of the fall and the winter, and the story of the third winter passed in the high north.

The climax of sympathetic interest is reached when Peary comes to tell of his second crossing of the ice-cap in the face of unusual difficulties, and of the scant margin by which he escaped several threatened sources of disaster. The objects and results of the expeditions of 1893–5 are summarized as follows:

Objects. — The delimitation of the detached lands lying north of main Greenland; the filling in of the remaining gaps in the northern and northeastern coast line of Greenland; in the event of favorable conditions, an attempt upon the Pole; the completion of the detail survey of the Whale Sound region; continuation of the studies of the Smith Sound Eskimos; the discovery of the "Iron Mountain."

Results. — The crossing of the inland ice-cap of north Greenland under a most serious handicap of insufficient provisions; the completion of the detail survey of Whale Sound; large accessions of material and information in connection with the Smith Sound Eskimos; the discovery of the "Iron Mountain" or Cape York "Saviksue," and the bringing home of two of those interesting meteorites.

The work is completed by the narrative of the two summer voyages made in 1896 and 1897, whose chief object was the bringing home of the great Cape York meteorite, which was successfully accomplished by the latter expedition.

The work is written in clear and graphic style, and the story is followed with ease and satisfaction by the reader. The narrative moves forward at a steady and rather rapid pace, and is unusually free from tedious passages. The size of the work is not due to needless deployment of details or the introduction of much subjective matter. It is merely an expression of the great amount of work which Lieutenant Peary has done. His aim has been, as stated in the preface, to condense and to avoid all padding. In the main he has avoided exploiting his feelings, a practice quite too much the fashion with Arctic explorers. When he has given them expression it has usually been on occasions that specially invited it, and then with brevity and good taste.

The scientific reader will of course wish that the natural phenomena of that wonderful region had been set forth with greater detail and with more special reference to their scientific bearings, but this would doubtless have been less acceptable to the great mass of readers

for whom the work was written. There is a hint that the scientific results will be specially treated in some later work. The scientist will, however, find this work rich in phenomena of the highest interest, not less in the illustrations than in the text. No work on the great white north has ever been so amply and so accurately illustrated as this. The 800 photographic illustrations tell their own story. Lieutenant Peary was as fortunate as he was industrious in making an unassailable photographic record of his explorations. Neither storms, dangers, nor stress of circumstances seem to have stopped the work of his ever-present kodak. The mechanical execution of the half-tones, while in the main fair, yet leaves something to be desired. Their extreme value would have warranted the use of the best available paper and of the utmost skill in printing. Their execution is sufficiently good, however, to lend an inestimable value and interest to the text.

T. C. C.

United States Geologic Atlas, Folio 41, Sonora, California. 1897.

The folio consists of seven pages of text signed by H. W. Turner and F. L. Ransome, geologists, a topographic map of the district, an historical geology sheet, an economic geology sheet, and a structure section sheet.

The quadrangle represented in this folio lies between the parallels of 37° 30′ and 38° north latitude, and meridians of 120° and 120° 30′ west longitude. It comprises a portion of the western slope of the central Sierra Nevada, chiefly in the foothill region. The quadrangle covers portions of Tuolumne and Mariposa counties, including, also, corners of the valley counties of Stanislaus and Merced. The area is drained chiefly by the Tuolumne and Merced rivers.

The formations are divided into two main groups: The bedrock series, and the superjacent series. The bedrock series is composed of Juratrias and Palæozoic sediments with interbedded lavas and tuffs, and a series of old igneous rocks, chiefly quartz-diorites, serpentine derived from peridotite, and porphyries. The Juratrias rocks are chiefly clay-slates with some sandstone, and are called the Mariposa formation, since the characteristic Jurassic fossils of the formation were first found in Mariposa county. The Mariposa formation is represented by three distinct belts of slates, the most eastern belt of which is remarkable as containing in part the gold-bearing veins of

the mother lode. The Palæozoic sediments are called the Calaveras formation. The only evidence of the age of this formation in the limits of the quadrangle consists in rounded crinoid stems found in limestone on Mormon Creek, but the formation is stratigraphically continuous with the Calaveras formation of the Jackson and Yosemite quadrangles, in both of which Carboniferous fossils have been found. The pre-Cretaceous rocks in general are very similiar to those of other portions of the Gold Belt, but two rock types occur here that are rare elsewhere. These two types are certain soda-feldspar dike rocks, called soda-syenite, and a hornblende-pyroxene rock. The soda-feldspar dikes occur chiefly along the mother lode and at many points have been altered by mineral solutions which have deposited calcite, dolomite, pyrite and some gold and silver. East of Jacksonville, at Kanaka Creek, and east of Moccasin Creek, these dike rocks have been extensively exploited for gold. The soda-feldspar dikes (soda-syenite) of the Sonora quadrangle are practically the same as the soda-syenite which forms the lode of the Treadwell mine on Douglas Island in Alaska. The hornblende-pyroxene rock, above referred to, is chiefly remarkable as being apparently unique. The hornblende forms porphyritic crystals in a finer ground mass of augite and hornblende.

The superjacent series is composed of Eocene beds, Miocene beds, andesitic sandstone, auriferous gravels, and various lavas. All of the rocks of the bedrock series were greatly eroded during Cretaceous and early Tertiary time, and upon this old surface of erosion, or approximate peneplain, the river gravels and lavas of the superjacent series were deposited. During Cretaceous and a large portion of Tertiary time the San Joaquin Valley was under water. The sediments deposited at that time, which have been preserved in the Sonora quadrangle, consist of sandstone of Eocene age (Tejon formation), shale, sandstone, clay and rhyolitic tuff of supposed upper Miocene age (Ione formation), and coarse andesitic sandstones and conglomerates which are presumably of Pliocene age. The gravels deposited by the rivers of this period are called the Auriferous river gravels. These river deposits have very largely disappeared through erosion, but are still preserved at some points underneath the lavas of late Tertiary. The best preserved river channel is that underlying the Tuolumne Table Mountain west of Sonora. This mountain owes its table character to a dark basaltic rock (*latite*) which flowed down the valley of the Neocene

Tuolumne river. The low ridges that formed the sides of this Neocene river valley have since that time been worn away by the erosive agencies, leaving the river channel with its hard basaltic capping standing above the surrounding country. At many points tunnels have been run in under the lava capping to penetrate the gravels beds, which have proved highly auriferous at some points. Rhyolite lavas which are so abundant in the Sierra Nevada to the north of the Sonora quadrangle have been found here only in small amount intercalated in the beds of the Ione formation. The andesitic tuffs and breccias, which, at one time, must have covered a large portion of the northern half of the quadrangle, have largely disappeared. The Table Mountain basalt is evidently younger than a portion of the andesite, as it overlies andesitic tuffs and gravels.

Economic geology.— The Sonora quadrangle comprises a portion of the southern part of the mother lode gold district. This remarkable linear system of gold quartz veins extends across the quadrangle in a northwest-southeast direction, and lies partly within the eastern belt of the slates of the Mariposa formation and partly to the east of this belt. Many of the mines are now being operated with good results. Profitable gold quartz veins are also found in the bedrock series, both to the east and west of the mother lode district. The mines in the granodiorite east of Sonora have been worked with varying success for many years. The limestone of the Calaveras formation, which extends from Sonora to the southeast, has been largely metamorphosed into marble, much of which is valuable for building purposes. Chrome-iron deposits occur within the serpentine areas. The sandstones of the Ione and Tejon formations, along the borders of the great valley, are valuable for building stone. The forest zone of the northeastern portion of the quadrangle furnishes valuable timber for the mines and for building purposes.

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